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THE FEASIBILITY OF ESTIMATING AVIONICS SUPPORT COSTS EARLY IN THE ACQUISITION CYCLE

Volume I: The Basic Report

John D. Morgan
Aaron B. Fuller

September 1977

Prepared for

The Office of the Director of Defense Research and Engineering

INSTITUTE FOR DEFENSE ANALYSES
COST ANALYSIS GROUP

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IDA Paper P-1292, "The Feasibility of Estimating Avionics Support Costs Early in the Acquisition Cycle" in two volumes

Authors: John D. Morgan
Aaron B. Fuller

Volume I: The Basic Report

Page	Erratum
Cover	The Office identified as "Prepared for" should read-- Office of Assistant Secretary of Defense (Program Analysis and Evaluation)
S-15	Line of text missing at top of page: ...available in the Services and contractors. The least complex...
xvi	The second word of the IROS acronym is incorrect: it should read-- ...Reliability...
199	Eighth line from the bottom of page, 4th word, misspelled: it should read-- feasible
202	Seventh line from top of page, 6th word, misspelled: it should read-- cumulative

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This paper reports on research to determine the feasibility of developing methods to estimate, early in the system acquisition cycle, the potential support cost inputs of alternative avionics components envisioned for Air Force and Navy fighter aircraft. Support costs are defined as those costs incurred at the organizational, intermediate
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and depot levels to maintain avionics equipment and the costs of avionics spares and repair parts support.

The results of the study are presented in two volumes. Volume I reviews and evaluates current methods used in industry and in the Air Force and Navy to estimate these avionics support costs, reviews and evaluates relevant industry and defense studies; reviews industry and DoD data and management systems that could provide data needed for avionics support cost estimating techniques; discusses the feasibility of developing suitable estimating techniques; and presents recommendations on the best methods to follow in dealing with this cost estimation problem at DSARC 0, I, and II. The paper provides a comprehensive review of the DSARC process. It discusses major conceptual problems in developing estimates of future support costs for equipment still in the early development stages. Finally, the paper concludes that it is feasible and desirable to prepare these estimates for avionics support costs. The specific method to be adopted depends on the amount of resources OSD wishes to devote to this effort.

Volume II is a compilation of appendixes containing additional material to support the basic report, including summary evaluations of forty-eight key documents encountered in the literature search.

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September 1977

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Task DP&E 110

FOREWORD

This paper, prepared by the Cost Analysis Group of the Institute for Defense Analyses, reports on work accomplished for the Director, Planning and Evaluation, Office, Secretary of Defense (OSD/DP&E) under Task Order DP&E-110, January 3, 1977.

The objective of this research was to determine the feasibility of developing methods to estimate, during system acquisition, the support cost impact of alternative avionics components envisioned for Air Force and Navy fighter aircraft. For the purpose of this study support costs are defined as those costs incurred at the organizational, intermediate, and depot levels to maintain avionics equipment and the costs of avionics spares and repair parts support.

Currently, the OSD Cost Analysis Improvement Group (CAIG) lacks the capability to evaluate the sensitivity of avionics support costs to alternative avionics component designs, configurations and reliabilities. Moreover, there is considerable uncertainty regarding the approach that should be taken to estimate these costs in the early stages of aircraft system development. Research under this task was designed to aid DP&E in deciding what action to take to deal with this problem.

The task involved the following specific requirements:

(1) Review and evaluate current methods used in industry and by the Air Force and Navy to estimate the support costs of avionics equipment on operational aircraft systems.

(2) Review and evaluate relevant industry and defense studies that have addressed the problems of estimating support costs of avionics equipment prior

to operational deployment or may offer insights on how to develop suitable estimating techniques.

(3) Review industry and DoD data and management systems that may provide information that could be used in developing or applying estimating techniques for avionics equipment under consideration in the study.

(4) Based on research performed under (1) through (3), determine the feasibility of developing methods to estimate the support costs of avionics equipment during system development. Present recommendations on best methods to follow in dealing with this cost estimation problem at both DSARC I and II.

In satisfying the requirement of (1) above, IDA extended the analysis to include a complete review of current Air Force and Navy methods to estimate the relevant future avionics support costs very early in the weapon system acquisition cycle. Although knowledge of these methods exists throughout DoD, this paper documents, with relatively comprehensive coverage, the existing Service state-of-the art in cost estimating. Our evaluations also cover all of these methods.

Finally, we present our views on how OSD should address the problem of estimating future avionics equipment support costs when the equipment is in the very early stages of development.

Chapter I of this paper defines the areas of interest, and the avionics equipments relevant to our research. It also includes a description of the roles and the processes of the Defense Systems Acquisition Review Council (DSARC). Major conceptual problems exist in developing estimates of future support costs for equipments in the early development stage; This is particularly true for avionics equipment. Therefore, Chapter I discusses at some length these conceptual problems. Finally, we present a brief summary of our review of prior research related to the subject area of this task.

Chapter II includes the descriptions of current Air Force and Navy methods to estimate avionics support costs at all stages of the weapon system acquisition cycle. These methods vary from broad parametric regression techniques using scanty data and providing highly uncertain outputs to accounting methods that use data relating to the actual performance of fully developed equipments.

Chapter III discusses the methods used by defense contractors who perform analyses extending from early feasibility studies to evaluations of future support costs based on hardware in production. As would be expected, some of the most significant cost estimating research has been performed by contractors, especially since OSD has begun to place considerable emphasis in the acquisition process on the impact of future system support costs.

Chapter IV contains our evaluations of the Services' and contractors' estimating methods. The advantages and disadvantages of the various methods are well known in the defense community but, in this chapter, we attempt to focus on characteristics and capabilities of these methods as related specifically to avionics. The technological content and rate of technological change are very significant in avionics and these elements introduce special problems in support cost estimating for this kind of equipment. We discuss the implications of these characteristics.

Chapter V discusses modeling approaches that should be considered by OSD in addressing the avionics support cost estimating problem. Six methods are discussed with identification of special characteristics that OSD should consider in determining which methods might best fit their needs.

Chapter VI contains our conclusions on the feasibility of developing methods to estimate the support costs of avionics equipment during system development. In summary, we conclude

that it is feasible and desirable to prepare these estimates. The specific method to be adopted depends on the amount of resources OSD wishes to devote to this effort. This decision, of course, should relate to the degree of importance OSD chooses to attach to the support cost variables versus other variables such as performance in selecting among alternative major systems.

The appendixes of this paper contain extracts of directives, summaries of prior research documents, and details on various support cost estimating methodologies.

Periodic reviews and critiques of IDA's work were performed by a Technical Review Board (TRB) composed of Mr. J.J. Bussolini, Grumman Aerospace Company, Dr. Steve Dresner and Mr. Hyman Schulman of the RAND Corporation, and Dr. C. David Weimer, IDA Cost Analysis Group. We appreciate the constructive comments and recommendations of the Technical Review Board.

EXECUTIVE SUMMARY

A. THE INSTITUTE FOR DEFENSE ANALYSES TASK

The Director of Planning and Evaluation in the Office of the Secretary of Defense asked IDA to ascertain the feasibility of developing methods to estimate the future support costs of avionics equipments on proposed fighter aircraft while the aircraft are still being planned and developed. As a general definition, avionics refers to radios, radars, computers, antennas, pulse analyzers and other airborne electronics equipments that perform the specific aircraft functions shown in Table S-1.[1] Support costs in this paper refer to maintenance costs at the organization, intermediate, and depot levels and to the costs of spares and repair parts.

The paper presents the following research results:

(1) It reviews and evaluates current Navy, Air Force, and industry methods used to estimate the support costs of avionics equipment on operational aircraft.

(2) It reviews and evaluates relevant industry and defense studies that have addressed the problems of estimating avionics support costs during the acquisition process prior to operational deployment.

(3) It reviews relevant DoD and industry data and management information systems that can provide information useful to avionics support cost estimates during the acquisition cycle.

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[1]Two-digit Work Unit Codes (WUC's) such as those in Table S-1 identify basic functions that are performed on aircraft. The WUC system, defined in MILSTD 780, is the coding structure for identifying equipment to maintenance actions performed at the organization and intermediate levels in the Services.

Table S-1. AVIONICS COMPONENT EQUIPMENT CATEGORIES IN THE DOD TWO-DIGIT WORK UNIT CODE (WUC) SYSTEM

Work Unit Code	Avionics Component Equipment Category
51	Instruments
52	Autopilot
53	Guidance Systems (Drone)
54	Telemetry System
55	Inflight Recording System
56	Flight Reference
57	Integrated Guidance and Flight Control
58	Inflight Test Equipment
59	Target Scoring and Augmentation
61	HF Communications System
62	VHF Communications System
63	UHF Communications System
64	Interphone System
65	IFF Systems
66	Emergency Radio
67	Integrated COM-NAV-IFF Packages
69	Miscellaneous Communications
71	Radio Navigation
72	Radar Navigation
73	Bombing Navigation
74	Weapons Control
75	Weapons Delivery
76	Electronic Countermeasures

(4) It affirms the feasibility of developing methods to estimate avionics support costs during weapon system development prior to operational deployment. Based on this feasibility determination, it recommends methods for OSD to consider for the development of an OSD-level avionics component support costing capability.

B. BACKGROUND

The costs of supporting a modern fighter aircraft throughout its operational life have become large relative to the aircraft's acquisition cost. Because the largest share of support cost dollars are spent to maintain components and to buy component spares and repair parts, those support cost categories have become items of interest to DoD decision-makers responsible for the acquisition of new weapon systems like fighter aircraft. In order to recognize and consider these support costs in planning, developing, and acquiring a new weapon system, estimates of these costs are required at the appropriate decision milestones.

The appropriate milestones seem to be those that occur in the early development stages of a new fighter aircraft program, including the informal conceptual study milestone and the formal program initiation and the validation and demonstration milestones. All of these milestones occur prior to the source selection decision when the military Service source selection authority decides which of the competing commercial firms will be funded to build prototype aircraft for full scale engineering development testing. Currently the contractors do not present to the Services, and the Services do not present to OSD, estimates of the support costs for individual avionics components before the source selection decision. But by the time the source selection decision is made, many of the engineering support and design decisions have been made that will determine the costs of supporting the component equipments when the aircraft becomes operational. Some contractors estimate that as much as 70% to 80% of the total life cycle costs of an aircraft are determined by the decisions made prior to source selection. The conclusion is that the importance of these early decisions dictates that OSD have new support cost estimating capabilities appropriately designed to fit the needs of decision-makers at each system acquisition milestone.

Given this requirement, we conducted our research on the assumptions that OSD requires both an independent estimating capability to validate component support cost estimates presented to it, and an independent trade-off study capability to compare the costs of alternative equipments that could fulfill a given functional capability on a proposed aircraft. In order to determine the feasibility of developing methods to provide these estimates, it was necessary to understand the Service and contractor component support cost estimating capabilities.

C. SERVICE AND CONTRACTOR AVIONICS COMPONENT SUPPORT COST ESTIMATING CAPABILITIES

The cost estimating methodologies available to the Services and contractors include

(1) engineering "bottoms-up"
(2) analogy with existing systems
(3) accounting add-up
(4) simulation
(5) parametric regression
(6) subjective expert judgments.

The Services especially rely on accounting add-up models and parametric regressions, while the contractors may use all of the approaches throughout a development program. The contractors place particular emphasis on analogies to existing systems, engineering bottoms-up pricing, and the subjective expert judgments of their design and support engineering personnel.

A good example of the Services' accounting model approach is provided by the Air Force Logistics Command Logistic Support Cost (LSC) Model. Using nearly one hundred different input variables for each piece of component equipment, the model calculates costs in ten support categories including spares (initial and replenishment) and maintenance (field and depot).

The equation to calculate "on-equipment" maintenance costs at the field organization and intermediate levels is shown in Figure S-1. As can be seen in this typical accounting equation structure, values for both contractor-furnished inputs (MTBF, RMH, RIP, IMH, PAMH, QPA) and government-furnished inputs (TFFH, UF, BLR, SMI) are combined in simple algebraic expressions that permit the support cost per unit of equipment to be calculated and then summed for the number of units of equipment required.[1] This is the essence of the accounting approach, and it is reflected in this Air Force LSC model as well as the Navy's Equipment Life Cycle Cost Model, the Cost Reduction is Everyone's Responsibility (CRIER) Model, and other accounting models that we examined.

The parametric regression approach is usually used by the Services to estimate total aircraft support costs and the support costs of the three basic aircraft elements, the airframe, engine, and avionics. These aggregate high level estimates can then be allocated or factored to individual components such as avionics equipments. The Navy most recently has used this approach for its F-18 development program. A typical equation calculates the component rework cost per flying hour as shown below:

$$CRC = 105.673 + 31.918[0.74(AF) + (AV+PROP)] + 8.445 \left(\frac{EW}{MFHBF}\right) - 0.053916\, V_{max} .$$

CRC = component rework cost per flying hour
AF = airframe flyaway cost
AV = avionics flyaway cost
PROP = propulsion flyaway cost
EW = empty weight
MFHBF = mean flight hours between failure
V_{max} = maximum aircraft velocity

[1] The acronyms in parenthesis are spelled out in Figure S-1.

The equation was developed from historical cost and aircraft characteristics data on nine Navy aircraft. The calculated result for the estimated F-18 values of the variables was a component rework cost of $200 per flying hour. This $200 was then allocated to various equipment components on the basis of factors derived from the component rework cost experience on the most similar existing Navy aircraft. It must be stressed that these allocations of costs to components were used only by the Navy as an internal Navy method for establishing a baseline against which contractor reported costs could be compared. The baseline itself was never intended as an estimate of actual component support costs. It is of interest to us because it highlights the fact that parametric regression equations for the support costs of individual components are not currently used by the Services. Instead, individual component costs are factored or allocated.

Costs calculated with the Air Force LSC equations and the Navy parametric regression equations are currently presented for Service source selection decisions and for OSD full-scale engineering development decisions. But prior to these stages of the acquisition process these equations, which represent the state-of-the-art in Service component support cost estimating, are not presented to OSD for evaluation.

Contractor component cost estimating capabilities are firmly grounded in the cumulative engineering experience of the various airframe and avionics firms. As shown in Table S-2, the common sequence of contractor avionics component support cost estimating procedures is iterative, involving detailed engineering judgements of the design and reliability and maintainability impacts on support costs. Because these judgments are based on real world experience with the fundamental cost drivers as they relate to equipment design, the contractors have the basic knowledge to apply to any and all of the six basic cost methodologies listed earlier.

1. C_2 = cost of on-equipment FLU[1] maintenance = $C_{21} + C_{22}$

Where: C_{21} = manhour cost to perform on-equipment (flight line) m
system life.

C_{22} = manhour cost to perform scheduled maintenance on the

2. $$C_{21} = \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} [PAMH_i + (RIP_i)(IMH_i) + (1-RIP_i)(RMH_i$$

A
Fraction
On-time corrective
Fraction of failed FLU's
In-place preparation and access
Ratio of operating to flying hours
Number of like FLU's in parent syste
Mean time between failure
Total force flying hours
Total number of FLU's in system

3. $$C_{22} = \frac{TFFH}{SMI} (SMH)(BLR)$$

Base labor rate
Average manhours to perform scheduled peri
Flying hour interval between scheduled per
Total force flying hours

[1]A First Line Unit (FLU) is the first level of assembly below the two-digit Work Uni
at base level. It is usually the highest level of assembly that is removed and rep
equipment to an operational condition. A lower level sub-assembly within a FLU, ca
at intermediate level shops is not defined as a FLU.

[2]The term RIP_i, repaired in place, is a number giving the fraction of failed FLU's r
fraction of failed FLU's not repaired in place.

[3]The variables in this bracketed term constitute the weighted average on-equipment m
and access time and either in-place repair or removal and replacement.

Figure S-1. *ON-EQUIPMENT MAINTENANCE COST* EQUATION IN THE AFLC LO

$1 + C_{22}$

ent (flight line) maintenance on FLU's due to unscheduled failures over the

maintenance on the complete system over the life cycle.

$H_i) + (1-RIP_i)(RMH_i)](BLR)$

→ Base labor rate

→ Average manhours to fault isolate, remove and repair

→ Fraction of failed FLU's repaired in place[2]

→ On-time corrective maintenance manhours

tion of failed FLU's repaired in place

paration and access manhours [3]

g to flying hours

U's in parent system

failure

g hours

LU's in system

form scheduled periodic or phased inspection

tween scheduled periodic or phased inspection

s

the two-digit Work Unit Code (WUC) equipment level that is carried as a line item of supply that is removed and replaced on the complete system or sub-system in order to return the sembly within a FLU, called a Shop Replaceable Unit (SRU), that is repaired or replaced only

ction of failed FLU's repaired in place. The complete term $1\text{-}RIP_i$, is a number giving the

average on-equipment maintenance manhours per failure of the i^{th} FLU including preparation placement.

ON IN THE AFLC LOGISTIC SUPPORT COST MODEL

2

Table S-2. COMMON SEQUENCE OF CONTRACTOR AVIONICS SUPPORT COST ESTIMATING PROCEDURES DURING CONCEPTUAL AND VALIDATION STAGES

Step	Type Firm	Cost Estimating Activity
1	Aircraft Prime Contractor	Uses analogy or parametric regressions to estimate avionics support costs as a single lump, not broken out by pieces of equipment.
2	Aircraft Prime Contractor	Requests acquisition and support cost estimates and support parameters such as MTBF for types of equipment from avionics producers.
3	Avionics Equipment Producer	Engineering bottoms-up or analogy estimates of acquisition and support costs and support parameters such as MTBF for specific equipments, reported to prime contractor.
4	Aircraft Prime Contractor	Uses accounting build-up or parametric estimates with avionics equipment producers estimates and support parameters as inputs.
5	Avionics Equipment Producer	Uses aircraft prime contractor total aircraft weapon system estimates as inputs to modify analogy and engineering estimates, reports up-dated estimates to aircraft prime contractor.
6	Both Avionics Equipment Producer and Aircraft Prime Contractor	Continue to iterate cost models by inputting each other's updated data and reporting iterations to each other. In this process, all cost estimating methodologies may interact through iterative processes.

Contractor misgivings about the development of OSD-level avionics component support cost estimating capabilities include doubts about the utility of the resulting cost estimates to OSD and the Services, and concerns that early conceptual stage cost estimates might become hard numbers to which the contractors would be expected to manage.

Current study contracts between the Air Force Avionics Laboratory and Westinghouse Electric Corporation and the Air Force Flight Dynamics Laboratory and Grumman Aerospace Corporation provide examples of the applications of engineering experience and expertise to component support cost estimating. Both contracts seek to develop parametric equations that can estimate component support costs in the relevant categories including maintenance at all levels and spares and repair parts. Our discussions with the Westinghouse and Grumman personnel reveal that their fundamental approaches are similar in that they rely on their in-house design and reliability and maintainability experts to assess the relevant cost drivers that lie behind component support costs. The major difficulty faced in both contracts lies in the gathering, processing, and understanding of the historical support costs and aircraft characteristics data. This is important because it suggests that the basic methodology for component support cost estimating exists. What is required is an adequate data base.

D. DATA SYSTEMS

Service component support cost data systems are designed for the management of resources, not for the accumulation of consistent cost data that can provide the bases for support cost analyses in the various methodological approaches. This situation is changing with the development of data reporting systems like the Visibility of Management and Support Cost (VAMOSC) systems in the Air Force and Navy. The Air Force's Operating and Support Cost Estimating Reference (OSCER) system

does not yet provide cost visibility to the component level, but a component cost companion system to OSCER is under development. The Naval Air Logistics Command Management Information-Operating and Support/Visibility and Management of Support Cost-Air (NALCOMIS-O&S/VAMOSC-AIR) data system has a Maintenance Subsystem that reports component equipment costs in the categories shown in Table S-3. Based on actual field and depot cost data, the NALCOMIS Maintenance Subsystem promises to provide the detailed support cost visibility necessary to successfully implement existing component cost methodologies in the Services and contractors.

E. FEASIBLE MODELING APPROACHES FOR THE OSD-LEVEL

Based on our examination and analysis of Service and contractor methodologies, current work underway to refine these methodologies, and currently emerging data information systems, we concluded that is is feasible to develop methods for avionics component support cost estimating at the OSD-level.[1] Table S-4 identifies six major approaches as logical alternatives for an OSD-level capability, and narrows to four those that are most feasible.

The bottoms-up and accounting approaches most widely used by the Services and contractors are rejected as infeasible because of their extremely large data input requirements at very detailed levels. These may be viewed as logical alternatives that are rejected because their implementation effectively requires duplication of the extensive Service and contractor capabilities.

The four feasible model approaches may be viewed as approximations to and substitutes for the detailed expertise

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[1]This paper did not address the subject of implementation of the recommended alternative models. Estimates of the cost of implementation are therefore beyond the scope of this paper.

Table S-3. COST ELEMENTS IN THE NAVY VAMOSC-AIR MS REPORT

Level of Detail	Cost Categories
Organization costs at 2-digit Work Unit Code Level of Detail	MAINTENANCE Labor scheduled Labor unscheduled Consumables scheduled Consumables unscheduled SUPPORT LABOR TECHNICAL DIRECTIVE COMPLIANCE LABOR
Intermediate costs at 2-digit Work Unit Code Level of Detail	MAINTENANCE Labor scheduled Labor unscheduled Consumables scheduled Consumables unscheduled SUPPORT LABOR TECHNICAL DIRECTIVE COMPLIANCE LABOR ATTRITION
Depot costs at 2-digit Work Unit Code Level of Detail	COMPONENT REPAIR ACTIONS NARF Direct labor Indirect labor Material Commercial SURVEYED REPAIRABLES TECHNICAL DIRECTIVE COMPLIANCE LABOR
Costs reported only as sums for entire aircraft, not for each 2-digit Work Unit Code	PRE-EXPENDED MATERIAL ORGANIZATIONAL SUPPORT LABOR TECHNICAL DIRECTIVE COMPLIANCE MATERIAL COSTS Organization Intermediate Depot

Table S-4. SUMMARY

Model	Type	Existing Examples	Req Analytic
Estimation Model 1	Bottoms-up and Analogy	Basic contractor approach after DSARC 0	Initial ana engineering a continual model is be
Estimation Model 2	Traditional regression approach with acquisition cost as one of a few independent variables	GRC models	Initial ana existing hi base
Estimation Model 3	Regression and Bottoms-up analogy combined	Some contractor research being done to develop such models	Initial en analysis a continual support in data base
Estimation Model 4	Accounting and Analogy	AFLC LSC, Navy LCC, CRIER	Analytical process ma inputs
Estimation Model 5	Regression	None	Initial an to work hi base
Estimation Model 6*	Proprietary Regression (RCA PRICE)	RCA PRICE-L	Initial tr operator, required t

*The RCA PRICE model alternative differs from the other alternatives in that the equations are relationships in the equations.

SUMMARY OF SUGGESTED MODELING APPROACHES FOR OSD-LEVEL

Required Analytical Support	Lowest Level of Detail in Model	Useful for Point or Trade-Off Cost Estimates	Feasibility for
tial analysis and then ineering judgments on ontinual basis while el is being utilized	7-Digit WUC Equipments	Point and Trade-off	Not feasible -
tial analysis of sting historical data e	2-Digit WUC Equipments	Point	Feasible after research to de suitable data equations
tial engineering lysis and then tinual engineering port input to update a base	7-Digit WUC Equipments	Point and Trade-off	Feasible after research to de suitable data equations
lytical support to cess massive data uts	7-Digit WUC Equipments	Point and Trade-off	Not feasible -
tial analytical effort work historical data e	2-Digit WUC Equipments	Point and Trade-off	Feasible after the basic mode
tial training of model rator, same operator uired to input data	7-Digit WUC Equipments	Point and Trade-off	Feasible but outputs very

ions are unknown to the model user. Only RCA knows the equations. This prohibits the user from assessing the

2

DELING APPROACHES FOR OSD-LEVEL

Lowest Level of Detail in Model	Useful for Point or Trade-Off Cost Estimates	Feasibility for use at OSD
7-Digit WUC Equipments	Point and Trade-off	Not feasible - too detailed
2-Digit WUC Equipments	Point	Feasible after initial research to develop suitable data base and equations
7-Digit WUC Equipments	Point and Trade-off	Feasible after initial research to develop suitable data base and equations
7-Digit WUC Equipments	Point and Trade-off	Not feasible - too detailed
2-Digit WUC Equipments	Point and Trade-off	Feasible after establishing the basic model
7-Digit WUC Equipments	Point and Trade-off	Feasible but validity of outputs very uncertain

user. Only RCA knows the equations. This prohibits the user from assessing the functional

approach is Model 2 in Table S-4, the traditional regression approach with acquisition cost of the equipment as an independent variable. Based on newly emerging VAMOSC data, equations developed along traditional lines may provide acceptable point estimates of avionics component support costs that could be used to validate estimates submitted by the Services. However, it is unlikely that such equations will be sensitive to design differences between alternative equipments, so other methodologies are required to provide a trade-off estimating capability.

The RCA PRICE models provide a component support cost trade-off capability, but require a blind acceptance of proprietary equations that are not revealed to the user. A better alternative in terms of visible equations is represented by Model 3 in Table S-4, a combination of regression and bottoms-up analogy approaches. The procedure would be first to establish an avionics data base that contains physical data characteristics of avionics equipments--size, weight, number of parts, and so on. Through a data system like the Navy NALCOMIS Maintenance Subsystem, the next step would be to accumulate detailed cost data for these equipments. Given these physical and cost characteristics of avionics equipments, it becomes possible to run regressions on selected pieces of avionics equipments with organization, intermediate, and depot level maintenance costs, and replenishment spares costs as dependent variables, and physical equipment characteristics as independent variables.

To use this approach as a regression analogy data base, the following procedure is possible. Assume a new F-X aircraft is to have an avionics suite composed of equipments that can perform identifiable avionics functions. Take an equipment function such as radio navigation, and have an engineer or other knowledgable person select various equipments from the data base that are closest analogies to the F-X equipment.

The support costs for these analogy equipments can be extracted from the data base and regressions can be run. By combining analogies selected by engineers or other experts, a set of parametric equations can be tailored to the requirements of the new F-X aircraft. This tailoring feature provides a flexible methodology. Each time a new F-X aircraft is proposed, a new set of closest analogy regression equations can be extracted from the data bases. Such a tailored regression analogy approach could provide both point and trade-off estimating capabilities.

IDA concludes that it is technically feasible and desirable for OSD to possess a capability for independent estimates of avionics support costs. The most suitable method would combine regression analysis and analogy but an approach based only on regression analyses could be adopted.

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FIGURES

TABLES

GLOSSARY OF ABBREVIATIONS

ACF	Air Combat Fighter
ACMS	Advanced Configuration Management System
AFAL	Air Force Avionics Laboratory
AFLC	Air Force Logistics Command
AFM	Air Force Manual
AFSC	Air Force Speciality Code
AFSC	Air Force Systems Command
AFTEC	Air Force Test and Evaluation Center
AGE	Aerospace Ground Equipment
AGMC	Aerospace Guidance and Metrology Center
ALC	Air Logistics Center
ASD	Aeronautical Systems Division
ASO	Aviation Supply Center
AVISURS	Aerospace Vehicle Inventory Status and Utilization Reporting System
BCM	Beyond Capability of Maintenance
CACE	Cost Analysis Cost Estimating
CAIG	Cost Analysis Improvement Group
CASEE	Carrier Aircraft Support Effectiveness Evaluation
CDRL	Contract Data Requirements List
CER	Cost Estimating Relationship
CFA	Cognizant Field Activity
COM	Communication
COND	Condemnations
CRIER	Cost Reduction Is Everyone's Responsibility
DCP	Decision Coordinating Paper
DMIF	Depot Maintenance Industrial Fund
DMMH	Direct Maintenance Manhours

DOD	Department of Defense
DODD	Department of Defense Directive
DP&E	Director, Planning and Evaluation
DSARC	Defense System Acquisition Review Council
EBO	Expected Backorders
ELCC	Equipment Life Cycle Cost
EOQ	Economic Ordering Quantity
ETI	Elapsed Time Indicator
FH	Flying Hours
FLIR	Forward Looking Infra-Red Radars
FLU	First Line Unit
FRS	Fleet Readiness Squadron
F-X	Fighter-Experimental
HF	High Frequency
ICA	Independent Cost Analysis
IDA	Institute for Defense Analyses
IFF	Identification Friend or Foe
ILS	Integrated Logistic Support
IMU	Inertial Measurement Unit
IOT&E	Initial Operational Testing and Evaluation
IROS	Increase Liability of Operational Systems
IRU	Inertial Reference Unit
LANTFLT	Atlantic Fleet
LCC	Life Cycle Cost
LCOM	Logistics Composite Model
LOR	Level of Repair
LORA	Level of Repair Analysis
LSC	Logistic Support Cost
LRU	Line Replaceable Unit
MAF	Maintenance Action Form
MAJCOM	Major Command
MCAIR	McDonnell Aircraft Company
MDC	Maintenance Data Collection
MDS	Model Design Series

MENS	Mission Element Need Statement
MFHBF	Mean Flying Hours Between Failure
MFHBMA	Mean Flying Hours Between Maintenance Actions
MILSTD	Military Standard
MMH	Maintenance Manhours
MS	Maintenance Subsystem
MSD	Maintenance Subsystem Detail
MSO	Maintenance Support Office
MTBF	Mean Time Between Failure
NADC	Naval Air Development Center
NALCOMIS	Naval Air Logistics Command Management Information System
NARF	Naval Air Rework Facility
NARM	Navy Resource Model
NATO	North Atlantic Treaty Organization
NAV	Navigation
NAVAIR	Naval Air Systems Command
NDCP	Navy Decision Coordinating Paper
NET	Naval Education and Training
NIIN	National Item Identification Number
NRTS	Not Repairable This Station
OASD/PA&E	Office of the Assistant Secretary of Defense, Program Analysis and Evaluation
O&S	Operating and Support
OJCS	Office of the Joint Chiefs of Staff
OR	Operational Requirement
ORLA	Optimum Repair Level Analysis
OSCER	Operating and Support Cost Estimating Reference
OSD	Office of the Secretary of Defense
OSD/PA&E	Office of the Secretary of Defense, Director, Planning and Evaluation
PACFLT	Pacific Fleet
PAR	Progressive Air Rework
PDLM	Programmed Depot Level Maintenance
PMA	Project Manager, Air

POL	Petroleum Oil and Lubricants
POM	Program Objective Memorandum
PPBS	Planning, Programming, Budgeting System
PRICE	Programmed Review of Information for Costing and Evaluation
R&D	Research and Development
RFP	Request for Proposal
RFQ	Request for Quote
RIDF	Repairable Item Data File
ROC	Required Operational Capability
RTS	Failed FLU's
SAF	Support Action Form
SAR	Selected Acquisition Report
SECDEF	Secretary of Defense
SOW	Statement of Work
SPO	System Program Office
SRU	Shop Replaceable Unit
STK	Pipeline Spares
TDC	Technical Directive Compliance
TEMP	Test and Evaluation Master Plan
TLSC	Target Logistic Support Cost
TRC	Technology Repair Center
TSS	Total Support System
UHF	Ultra High Frequency
VA	Attack Version
VAMOSC	Visibility and Management and Support Costs
VF	Fighter Version
VHF	Very High Frequency
WSPD	Weapon System Planning Document
WUC	Work Unit Code

Chapter I

INTRODUCTION

This paper presents the results of Institute for Defense Analyses (IDA) research on methods to estimate, early in the acquisition cycle, the future support costs that can be expected for fighter aircraft avionics equipment when the aircraft become operational. Specifically, the research addresses the question of whether it is feasible to develop cost estimating methods that will produce results useful in OSD decision-making while avionics components are either not clearly defined or are in the very early stages of development. Support costs are defined as those costs incurred at the organizational, intermediate, and depot levels to maintain avionics equipment and the costs of avionics spares and repair parts support.

The IDA research was designed to support the work of the OSD Cost Analysis Improvement Group (OSD/CAIG). At the time of this study the CAIG lacked the capability to evaluate for the Defense Systems Acquisition Review Council the sensitivity of support costs to alternative avionics component designs, configurations, and reliabilities. Moreover, there was considerable uncertainty regarding the approach that should be taken in developing methods for estimating these costs in the early stages of aircraft system development.

In the following chapters we initially review the methods currently used by the Air Force and Navy to estimate future support costs for fighter aircraft avionics equipment. Then we examine the techniques used by contractors to develop these kinds of estimates. Included in our reviews are discussions

of the DoD and contractor data and management systems that could be used in developing or applying cost estimating techniques. Our review is limited to the time period that ends with the operational deployment of the aircraft.

After these reviews of methods we present a comparison and evaluation of these methods in terms of their ability to satisfy CAIG needs. Then we present some simple models for comparison of avionics equipment alternatives. Some of these models could be used pending the development of more comprehensive techniques for estimating support costs.

Finally, we present a summary with our conclusions on the feasibility of developing suitable methods to estimate future support costs for fighter aircraft avionics equipment while that equipment is still under development and perhaps even in a "paper" stage of development.

A. DEFINITION OF AVIONICS

The simplest definition of avionics is airborne electronics, but this is too general for our research which examines specific cost estimating approaches, models, and data systems relating to discrete pieces of fighter aircraft equipment. For example, the Air Force F-16 Combat Fighter target logistic support cost (TLSC) model[1] produces cost estimates at the level of first line unit (FLU)[2] equipments such as the radar digital signal processor in the fire control system. The presence of hundreds of FLUs in a modern fighter development program like the F-16 required us to construct a reasonably precise definitional structure within which detailed pieces of equipment could be

[1]The TLSC model is discussed in Chapter II.

[2]A FLU is the first level of assembly below the 2-digit Work Unit Code level that is carried as a line item of supply at base level. It is the highest level of assembly that is removed and replaced as a unit in order to return a piece of equipment to an operational status.

identified as avionics or not avionics. A further complication is the fact that there are several types of largely electronic aircraft equipments that are not considered to be avionics (i.e., air conditioning, pressurization equipment, ice control devices, lighting systems, and electrical power supply units).

Some DoD and avionics industry sources focus on communications, navigation, weapons control and delivery, and electronic countermeasures equipments as avionics. Other sources include additional categories such as inflight test equipment and flight reference systems. Table 1 lists the twenty-three equipment categories that provide complete coverage of all aircraft components that are usually identified as avionics. The categories are those in the Work Unit Code (WUC) maintenance action equipment identification structure used by the Services.[1]

The categories describe the basic functions performed by avionics equipment on aircraft, and thus provide one acceptable definition of avionics. Alternative definitions can be tailored to specific requirements and can be developed by excluding one or more equipment categories from the list. Our working definition of avionics in this study is the comprehensive alternative that includes all WUCs from 51 through 76 in Table 1.

Not all of the WUCs in Table 1 are assigned to any single aircraft type. This is shown in Table 1 for four fighter aircraft, where the Navy's F-18 fighter aircraft has thirteen of the twenty-three codes, the Air Force's F-16 ten, the F-14A

[1]The guiding reference for WUCs is MILSTD 780. Two digit WUCs such as those in Table 1 identify basic functions that are performed on aircraft. The WUC system is the coding structure for identifying equipment to maintenance actions performed at the organization and intermediate levels. Additional digits up to seven identify more and more detailed pieces of equipment below the 2-digit functional level. For example, on the Navy's A-4 aircraft, WUC 72, radar navigation, is broken down to more than 200 five and seven digit WUCs, such as WUC 72190 (terrain avoidance set AN/ARG153), and WUC 7239620 (pulse decoder on receiver-transmitter RT762/APN154 on radar beacon set AN/APN154). A more complete discussion of WUCs is presented in Appendix B.

Table 1. AVIONICS EQUIPMENT CATEGORIES ON FOUR FIGHTER AIRCRAFT

Work Unit Code	Equipment Category	Aircraft			
		F-18	F-16	F-14A	F-4N
51	Instruments	x	x	x	x
52	Autopilot				
53	Guidance Systems (Drone)				x
54	Telemetry System				x
55	Inflight Recording System		x		
56	Flight Reference	x		x	x
57	Integrated Guidance and Flight Control	x		x	x
58	Inflight Test Equipment	x		x	
59	Target Scoring and Augmentation				x
61	HF Communications System				x
62	VHF Communications Systems		x		
63	UHF Communications System	x	x	x	x
64	Interphone System		x	x	x
65	IFF Systems	x	x	x	x
66	Emergency Radio			x	x
67	Integrated COM-NAV-IFF Packages	x		x	x
69	Miscelleneous Communications			x	x
71	Radio Navigation	x	x	x	x
72	Radar Navigation	x		x	x
73	Bombing Navigation	x		x	x
74	Weapons Control	x		x	x
75	Weapons Delivery	x	x	x	x
76	Electronic Countermeasures	x	x	x	x

sixteen, and the F-4N nineteen. Thus, avionics refers to a large set of potential equipment categories from which various sub-sets of equipment categories can be selected to make up the avionics suites for different aircraft.

B. THE DP&E TASK ORDER

This study was undertaken at the request of the Office of the Secretary of Defense, Director, Planning and Evaluation (OSD/DP&E).[1] Specific study requirements include the following:

(1) Review and evaluate current methods used in industry and the Navy and Air Force to estimate the support costs of avionics equipment on operational aircraft systems;

(2) Review and evaluate relevant industry and defense studies that have addressed the problems of estimating support costs of avionics equipment throughout the acquisition process prior to operational deployment;

(3) Review relevant DoD and industry data systems that can provide information useful for acquisition cycle avionics support cost estimates;

(4) Determine the feasibility of developing methods to estimate the support costs of avionics equipment during system development prior to operational deployment. Based on this feasibility determination, recommend the best methods to follow in dealing with avionics support cost estimates at DSARC I and II.

The material to satisfy these study requirements is in the succeeding chapters of this paper, with additional relevant detailed descriptions of key institutional structures, data formats, information systems, and modeling techniques presented in several appendixes.

[1]OSD/DP&E became the Office of the Assistant Secretary of Defense for Program Analysis and Evaluation (OASD/PA&E) effective April 14, 1977. The original task order is referred to in this paper as DP&E-110, and the orginal sponsoring office is OSD/DP&E; however, the office title change requires that the conclusions and recommendations of this paper be directed to OASD/PA&E.

C. ASSUMPTIONS AND GUIDELINES

Before proceeding with our study, it was necessary to establish initial assumptions and guidelines to define the context within which avionics support cost estimating techniques are assessed in this research. These assumptions and guidelines are:

(1) Avionics support cost estimating is a process that draws upon several disciplines including statistics, accounting, engineering, economics, mathematics, and administration and management;

(2) Existing data and management information systems are to be used as elements in the feasibility determination to the maximum extent possible;

(3) Several studies are underway that address avionics and other component support cost estimating processes. IDA must be alert to the results of these studies as they become available as potential tools for recommendataion to OSD;

(4) Recommended avionics support cost estimating methods should be the best conceptually available regardless of whether they are currently exercised by a specific modeling technique or not;

(5) Although not necessarily desirable, cost estimating methods recommended for use early in the acquisition cycle may provide less detailed equipment level estimates than methods recommended for later in the acquisition cycle when equipment system definition is greater;

(6) Warranty cost impact is not explicitly considered, although implicitly it is because analytical techniques and capabilities available in the Services and contractors are the same whether warrantied or unwarrantied equipments are under discussion. Specific applications of these basic costing techniques and capabilities to warranties are beyond the scope of this paper;

(7) This paper did not address the subject of implementation of the recommended alternative models. Estimates of the cost of implementation are therefore beyond the scope of this paper;

(8) The usefulness of specific models to OSD is not assessed in the sense that one model is identified as more or less useful than another model. This

is because usefulness is defined for specific purposes, and a model that may be useful in one context may not be in another. However, the circumstances under which the various models are most appropriate are discussed in the presentation and evaluation of contractor and Service methodogies.

D. APPROACH AND SCOPE OF RESEARCH

In undertaking research on this task we initially reviewed available literature to develop information on major conceptual approaches to the problem. We did not attempt to examine every study or document that relates in any way to avionics support cost estimating. Our focus was in conceptual approaches and our research was thorough in this area.

Having reviewed the literature in this area, we then visited key Navy and Air Force activities to discuss their experience and their methods for dealing with the problems encompassed by our task order. We secured Service views on the feasibility of preparing reasonable avionics support cost estimates very early in the acquisition cycle.

Our next step was to visit major fighter aircraft and avionics contractors to determine their support cost estimating techniques. We also consulted with representatives of other research firms to discuss their relevant research and gain insights on possible conceptual approaches.

We believe that our field research was sufficiently thorough to permit us to define the conceptual approaches that represent the state-of-the-art in avionics support cost estimating. As would be expected, there is a great degree of similarity in methods used in private industry and in the Services. Differences relate primarily to the level of detail considered in the various methods rather than in basic conceptual approaches.

E. THE ROLE OF THE DSARC IN THE DOD MAJOR SYSTEM ACQUISITION PROCESS[1]

The Defense Systems Acquisition Review Council is an advisory body to the Secretary of Defense (SECDEF) on major system acquisitions. The DSARC functions as part of a formal DoD system to ensure that the Secretary of Defense is informed of progress on new major system acquisitions and has the opportunity to decide at strategic program milestones whether the acquisitions should proceed into the next phase.[2] The system also permits the Secretary of Defense to establish performance, cost and schedule targets for these programs.[3] At prescribed milestones in the major system acquisition cycle, the DSARC reviews Service proposals and provides its recommendations to the SECDEF. Table 2 shows the DSARC decision milestones.

The Cost Analysis Improvement Group advises the DSARC on matters related to cost.[4] Among the CAIG responsibilities are the tasks of reviewing and evaluating independent and program cost estimates prepared by the Services for presentation at each DSARC review. The CAIG also must prepare cost estimates on different components and systems for the DSARC when that council is considering alternative ways to satisfy DoD mission requirements.

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[1]The acquisition process is also referred to as the DSARC process, although the Council itself is only one element of the process.

[2]SECDEF milestone decisions authorize the commencement of various steps in the acquisition process, but they do not authorize the commitment of funds. To seek budget approval and funding, the milestone decisions must be reflected in the Planning, Programming and Budgeting Systems (PPBS) documentation.

[3]Reference DoDD 5000.1, *Major System Acquisitions*, and DoDD 5000.2, *Major System Acquisition Process*, both dated January 18, 1977. See Table 2.

[4]Reference DoDD 5000.4, *OSD Cost Analysis Improvement Group*, June 13, 1973.

Table 2. CURRENT SECRETARY OF DEFENSE DSARC MILESTONES AND THEIR RELATIONSHIPS TO WEAPON SYSTEM ACQUISITION CYCLE PHASES

Current DSARC Decision Milestones and Acquisition Phases	
Decision Milestone	Acquisition Cycle Phase Initiated
DSARC-O: PROGRAM INITIATION DECISION This decision is based in part on the SECDEF's affirmation of an unfilled mission need.	CONCEPTUAL PHASE This phase follows and is authorized by an affirmative DSARC-O SECDEF decision.
DSARC-I: DEMONSTRATION AND VALIDATION DECISION This decision is based in part on the Conceptual Phase alternatives explored as solutions to the mission need affirmed at DSARC-O.	DEMONSTRATION AND VALIDATION PHASE This phase follows and is authorized by an affirmative DSARC I SECDEF decision.
DSARC-II: FULL SCALE ENGINEERING DEVELOPMENT DECISION This decision is based in part on the Demonstration and Validation Phase research on specific alternatives, and the resulting specific service source selection.	FULL SCALE DEVELOPMENT PHASE This phase follows and is authorized by an affirmative DSARC II SECDEF decision.
DSARC III: PRODUCTION AND DEPLOYMENT DECISION This decision is based in part on the test results generated by the flying of test aircraft during the Full Scale Development Phase. An initial production decision, called DSARC III.A, may be made for long lead production approval, followed later by a DSARC III.B decision which constitutes full production approval.	PRODUCTION AND DEPLOYMENT PHASE This phase follows and is authorized by an affirmative DSARC III decision (or decisions). Actual deployment of aircraft is authorized by the DSARC III decision and carried out during this phase.

1. **Milestone 0 - Program Initiation**

The individual Services conduct continuing analyses of their assigned mission areas to identify existing or projected capability deficiencies and opportunities to enhance capabilities through more effective and less costly methods and systems. These analyses are of interest to us here because they represent the first step in a process that may culminate in a major system acquisition. These mission area analyses may be conducted exclusively "in house," but more likely will be supported by contractors who conduct parts of the analyses through DoD-funded conceptual studies or through their own efforts to keep abreast of the latest developments. Contractors may also take the initiative and develop proposals for mission area capability improvements based on their own independent research programs. SECDEF guidance concerning mission area analyses is provided through Defense Guidance and Program Policy Memoranda.

When a Service identifies a new major mission area need, the Service prepares a Mission Element Need Statement (MENS). The MENS describes the mission and attempts to justify to the Secretary of Defense the initiation of a new major system acquisition to satisfy the mission need. To accomplish this justification, the MENS briefly (no more than ten pages) states the mission need in terms of the mission task to be performed, but this statement does not include capabilities and characteristics of hardware or software systems. The exclusion of capabilities and characteristics precludes cost estimates from routinely appearing in the MENS, unless the mission need identified is a cost saving opportunity. If the mission need were a cost saving opportunity, then the identification of the magnitude of the saving would be necessary, and details concerning hardware capabilities and characteristics related to

the potential cost saving could conceivably be entered as need justification material.[1]

If the Secretary of Defense approves a program to satisfy the mission need outlined in the MENS, he will specify conditions for the Service to proceed and state the basis for action to select options for demonstration and validation.[2] As shown in Table 2, program initiation approval constitutes the beginning of the conceptual phase of system acquisition. The Service concerned then publishes a formal Navy Operational Requirement (OR) or Air Force Required Operational Capability (ROC) document. During this conceptual phase the Service emphasizes competitive exploration of alternative systems to satisfy mission needs described in the OR or ROC without specifying in advance the explicit system characteristics.

2. Milestone I - Demonstration and Validation

The conceptual phase ends when the Service has decided which alternative or alternatives offer the greatest promise in terms of satisfying the mission need. Efficiency as well as effectiveness must be considered in reaching this decision. Thus, the cost and schedule variables must be evaluated with the performance variables in determining the most appropriate alternatives.

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[1] The MENS should also: 1) assess the projected threat through the time frame the capability is required; 2) identify existing DoD mission capabilities in the need area and identify deficienceis; 3) state the known constraints to any acceptable solution including operational and logistical, NATA requirements, investment limits, and so on; 4) assess the impact of not acquiring or maintaining the capability; 5) provide a program plan for the identification and exploration of competitive alternatives.

[2] Before the MENS is sent to the SECDEF for disposition, the DoD component head works with the Defense Acquisition Executive (identified in DoDD 5000.30, August 20, 1976, as the Deputy Secretary of Defense) to obtain comments on the MENS from the OSD staff and the Office of the Joint Chiefs of Staff (OJCS). When sent to the SECDEF, the MENS is accompanied by a position paper prepared by the Defense Acquisition Executive stating his assessment.

In order to secure a Secretary of Defense decision for further work, the Service prepares a Decision Coordinating Paper (DCP). This paper describes the alternative(s) recommended for demonstration and validation to meet the mission needs and discusses the projected resource investments as well as other characteristics associated with each alternative that was considered. The full range of Milestone I DCP program issues which the SECDEF must consider include whether or not

(1) the mission element task to be accomplished is still judged necessary as it was at Milestone 0;

(2) the threat assessment has been updated and is consistent with current evaluations;

(3) the alternative system design concepts adequately reflect the technology base and provide an acceptable competitive environment;

(4) foreign developments have been considered;

(5) the alternatives recommended for demonstration and validation meet the mission element needs;

(6) the established program constraints remain valid;

(7) the projected resource investment for the selected alternatives and other characteristics related to the alternatives are consistent with the stated constraints;

(8) operational and logistical considerations are adequate;

(9) use of available subsystems and existing military and commercial hardware and software are adequately considered;

(10) the acquisition strategy is complete, effectively integrates the program technical, business and management elements, and supports the achievement of program goals and objectives;

(11) short- and long-term business planning effectively supports the acquisition strategy;

(12) producibility and areas of production risks have been adequately considered;

(13) joint-Services, interoperability and multinational considerations are adequately treated in the planning;

(14) NATO standardization and interoperability requirements have been adequately considered;

(15) risk and uncertainty areas are identified and adequately treated in the planning;

(16) envirnomental considerations are adequate;

(17) planning and schedules for preparation of the Test and Evaluation Master Plan (TEMP) are adequate.

Currently, the SECDEF does not consider support cost estimates for avionics components when assessing the Milestone I issues identified above. However, the DCP goes through a staffing process of reviews and iterations before it is presented to the SECDEF and, during this period, quantitative judgments concerning costs for the entire aircraft or its major components, including avionics, may be introduced into the discussion of DCP issues.

The initial DCP planning meeting at the OSD level may occur several months prior to the Milestone I decision date. At this meeting the DSARC review date is established, the program alternatives to be considered are identified, and specific program issues and supporting information are discussed. Support cost issues could be introduced by any of the planning meeting members including the Defense Acquisition Executive representative[1] and the representatives of the other DSARC members,[2] Joint Chiefs of Staff, Director of Defense Research and Engineering, and the CAIG.

Following the meeting, the DoD component sponsoring the acquisition program prepares a "for comment" draft DCP to be

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[1]DoDD 5000.30, *Defense Acquisition Executive*, August 20, 1976. The Deputy Secretary of Defense is designated as the Defense Acquisition Executive.

[2]DSARC members include at a minimum the Defense Acquisition Executive, Director of Defense Research and Engineering, Assistant Secretaries for Program Analysis and Evaluation, Comptroller, Intelligence, Manpower, Reserve Affairs and Logistics, and the Director of Telecommunications and Command and Control Systems.

circulated through appropriate OSD staff offices for refinement and explanation of the issues. Component support cost estimates could be introduced as issues or elements of issues in this staffing process.

The for comment draft DCP with accompanying OSD staff comments is forwarded to the sponsoring component head from the Defense Acquisition Executive. The component then prepares a second draft DCP, a "for coordination" draft, distributed to the DSARC members fifteen days prior to the scheduled DSARC review. The DSARC examines the issues and prepares a report sent along with the DCP to the SECDEF for his decision.

If the SECDEF signs the DCP and issues an action memorandum, this constitutes a Milestone I (or DSARC I) approval of the Service's DCP recommendation, either completely or with modifications.[1] The Service proceeds to develop hardware and perform demonstrations of this hardware's capability to satisfy the mission need, and through these demonstrations validates the ability of an alternative or alternatives to meet the requirement proposed at DSARC's 0 and I.

The demonstration and validation phase concludes when the Service conducts a source selection and chooses the system to recommend to the SECDEF for a Milestone II full scale engineering development decision.

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[1]As a result of alternative design concepts examined during the conceptual stage, the DoD component head may conclude that the DSARC I DCP should contain one or a variety of hardware proposals for the demonstration and validation phase, proposals such as: 1) several alternative hardware systems; 2) one single hardware system; 3) demonstration and validation of alternative sub-systems for a single hardware system; 4) by-passing the demonstration and validation phase and going directly into full-scale engineering development. Thus, the SECDEF decision at Milestone I may be to proceed with one or several hardware or sub-system demonstrations before Milestone II.

3. Milestone II - Full Scale Engineering Development

To secure Secretary of Defense approval at Milestone II, the Service updates its DCP to present detailed information on the system it has selected in the source selection for full-scale engineering development. Based on this source selection, the DCP will now address the total program through completion including research and development, procurement, and operations.

The source selection that is incorporated into the DCP update for consideration in the Milestone II full-scale development go-ahead decision is the result of a detailed Service process.[1] The process may result in the selection of a single source, but it may also result in the selection of more than one source if multiple sources are desired, as would be the case if competitive prototypes are desired for the full-scale development phase. The selection is an integrated decision taking into account each offeror's technical approach, capability, management, design to cost, historical performance, life cycle cost, and other factors with the goal of selecting the contractor that is expected to do the best overall job for the government. This latter requirement means that no single factor, including life cycle cost and support costs as defined in this study,[2] should dominate the source selection process. However, component support costs can be important elements in the overall comparative evaluations of different contractors, and other things equal, may be the primary discriminating difference between a source selection winner and the losers.

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[1]See DoDD 4105.62, *Selection of Contractual Sources for Major Defense Systems*, January 6, 1976, for a detailed description of DoD policies concerning the competitive selection of contractual sources for the acquisition of major defense systems in accordance with the policies contained in the acquisition process described in DoDD 5000.1 and DoDD 5000.2. DoDD 4105.62 was amended as of March 3, 1977 to reflect the changes to DoDD 5000.1 and DoDD 5000.2, both dated January 18, 1977.

[2]Support costs are organization, intermediate, and depot maintenance costs, and spares and repair parts support.

Avionics component support costs may receive substantial attention in the selection of a new fighter aircraft contractual source for several reasons listed below.

(1) The avionics suite may be the prime difference between an existing operational aircraft and a new F-X aircraft in the Milestone 0 and I decisions.

(2) Given that the avionics suite is a high priority item, avionics support costs are substantial proportions of total support costs on existing systems and promise to be on new systems.[1]

(3) Support costs have grown to be the largest single element of total life cycle costs, so the avionics support costs on an F-X proposal submitted for source selection are of vital interest to DoD decision-makers charged with approving life cycle cost-effective defense acquisitions.

The technical requirements of a solicitation from a Service to potential contractors may be stated as technical goals, as acceptable values, or as bands of acceptable values in the cases where trade-offs are possible among performance characteristics, schedules, supportability, design to cost, and life cycle cost including component support cost. To facilitate the evaluation of these trade-offs, cost estimates that illustrate the impact of these trade-offs upon production and operating and support costs are required. The capability to assess these cost estimates, both for the Service and for OSD, is important for several reasons.

(1) The considerations of support and other costs promote integrated assessments of the capabilities of contractors to do the jobs they claim they can do. Without a capability to assess and verify the appropriate ranges of costs associated with alternative performances, designs, and components, the Services and OSD cannot produce a balanced appraisal of which contractor can do the best overall job for the government. To reemphasize an earlier point, it is essential to recognize that source selection is not dominated by a single criterion. Cost interacts

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[1]See Chapters II and III for discussions and examples of this issue.

with other characteristics to produce a picture of the contractor that can do the best job. As aircraft become more complex, especially in their avionics components, the necessity to assess costs at the component level grows more pressing.

(2) Trade-offs among alternative fighter aircraft designs may hinge on differences among and between components and their life cycle costs including support costs. To assess the impact on design, performance, and costs of substituting one radar for another in one or more F-X aircraft requires a quantitative functional linkage among these characteristics in the form of a mathematical computational technique.

When incorporating the source selection material into the revised DCP, the Service must assure the SECDEF that performance, cost and schedule estimates have been thoroughly reviewed and that they are well defined and consistent with the risks involved. The CAIG plays an active role in evaluating the source selection and in formulating recommendations to the Secretary of Defense for Milestone II decisions. DoDD 5000.1 prescribes that DCP performance, cost and schedule estimates shall not be formalized or considered firm prior to the Milestone II decision since systems are not adequately defined and the values for these system parameters remain uncertain during the early phases of the system acquisition process. However, when the Service selects the system for full scale engineering development, "...firm estimates for performance, cost and schedule shall be committed to documentation in the DCP." Thus, sufficient information should be available at Milestone II to permit the CAIG to validate the Service program office cost estimates that have been developed along with the contractor in the source selection process.[1]

[1]In addition to the DCP cost estimates formulated by the selected contractor and the Service program office, the Service develops an independent cost estimate to assist in determining the most probable development, production, and support costs. These estimates are prepared as part of the source selection process and are made available to OSD as part of the source selection documentation.

If the Secretary of Defense approves a full-scale engineering development of a major system at Milestone II, he establishes performance, cost and schedule values including estimates of probable variances at program completion. These values with their probable variances are identified as program thresholds. The entire Milestone II set of program issues include whether

(1) the mission element task to be accomplished is reaffirmed and the threat updated;

(2) the system selected meets the mission element needs, is cost-effective and is acceptable within stated constraints;

(3) NATO standardization and interoperability requirements are satisfied;

(4) the demonstration and validation results support the system recommended;

(5) system trade-offs have produced the most effective balance in cost, performance, and schedule including operational and logistical considerations, and life cycle cost considerations;

(6) uncertainties and risks have been identified and are acceptable; planning to resolve the remaining uncertainties and risks is adequate, and realistic fall-back actions and alternatives have been established;

(7) the acquisition strategy has been updated, effectively supports achievement of program objectives, and is being executed in the conduct of program management;

(8) short- and long-term business planning supports the strategy, and contract types are consistent with the program characteristics, risks, uncertainty and strategy;

(9) design to cost and life cycle cost requirements are realistic and effective in achieving cost objectives;

(10) cost, performance and schedule estimates and related thresholds have been thoroughly reviewed, and are well defined and consistent with risks involved. These values shall be established as firm estimates;

(11) action to submit the initial Selected Acquisition Report (SAR) is complete;

(12) planning for selection of major subsystems is clearly stated, provides for sustained competition to the maximum extent feasible and accepts the use of existing military and commercial hardware and software where appropriate. Foreign developments have been considered;

(13) demonstration and validation testing and evaluations have been completed and results support the recommendations;

(14) electronic/infrared/optical counter-measure performance requirements have been identified;

(15) producibility considerations and areas of production risks have been reviewed and the results found acceptable;

(16) requirements have been established for long-lead procurement items, initial limited production to support operational test and evaluation needs, and the verification of production engineering and design maturity and to establish the production base;

(17) the Test and Evaluation Master Plan (TEMP) identifies and integrates the testing and evaluation to be accomplished prior to the Milestone III program decision points;

(18) the program management structure and plan are sound and adequately supported.

4. Milestone III - Production and Deployment

When the full-scale engineering development phase is completed to include initial operational test and evaluation (IOT&E), the Service prepares its recommendations to the Secretary of Defense for the Milestone III production and deployment decision. This is accomplished by updating the DCP to include all of the relevant information to permit this decision to be made.

At this time schedule and cost estimates including operating and support costs should be realistic and acceptable. Design to cost and life cycle cost requirements should be identified. The selected system is considered affordable and remains the best alternative. Needless to say, all cost estimates should

be reasonably firm at this point since hardware has been defined and maintenance and supply support concepts have been determined.

If the SECDEF approves the Service proposal, the Service proceeds with contractual actions to procure the new major system and deploy it in the operating forces. Milestone III is the last formal milestone in the major system acquisition cycle. Subsequent reviews may be directed, however, using the forms and procedures of the DSARC processes just described. Some systems are of such importance in terms of cost or mission that the Secretary of Defense may desire to have further analysis and review that can be best provided through the DSARC system.

F. CONCEPTUAL PROBLEMS IN AVIONICS SUPPORT COST ESTIMATING

In implementing the major system acquisition review process, the DoD is faced with important problems relating to support costs. Although advanced procurements are required on some hardware, for example, spares, the weapon system support phase of an aircraft's life cycle begins with the operational deployment of units. However, the decisions made during the DSARC program review process prior to operational deployment largely determine the magnitude of these support costs. Life cycle cost researchers at Grumman Aerospace Corporation report that, based on Grumman's historical experience, 75% to 85% of the life cycle costs of an aircraft weapon system are determined by decisions made early in the conceptual phase near DSARC I.[1] Similar experience is reported by researchers at Boeing Aerospace Company, who found that 70% of the life cycle costs of Boeing aircraft programs were committed by the decisions made during conceptual planning.[2] These estimates are based on

[1] Bernard I. Rachowitz, Grumman Aerospace Corporation, *Designing to Cost (DTC/LCC)*, paper presented to the 36th Annual Conference of the Society of Allied Weight Engineers, Inc., May 1977.

[2] W.L. Johnson, R.E. Reed, Boeing Aerospace Company, *Maintainability/Reliability Impact on System Support Costs*, prepared for the Air Force Flight Dynamics Laboratory, December 1973.

fifteen year life cycles from development through procurement, operation, and retirement from the active fleet. Our discussions with other contractors revealed similar experience. This dominant life cycle cost impact of conceptual stage decisions is one reason why the Secretary of Defense has refined the weapon system acquisition process to include life cycle costs as explicit program decision parameters through the process.

Because support costs are the largest single category of life cycle costs, emphasis on one is consistent with emphasis on the other. Current life cycle cost estimates for the Navy F-18 and A-18 development programs attribute 44% of life cycle costs to operating and support costs, with another 12% attributed to initial support costs, for a total of 56%.[1] A comparable percentage is estimated for the Air Force F-16 program, where recurring and non-recurring O&S costs account for 58% of life cycle costs.[2]

Estimating future support costs for avionics is particularly difficult. Lt. Gen. Alton D. Slay, USAF Deputy Chief of Staff for Research and Development, has stated that "...in some modern aircraft, the avionics equipment costs upward of thirty percent of the total aircraft flyaway costs. Avionic support costs are equally high, approaching seventy-five percent of total support costs for some older aircraft with, in fact, avionics being the limiting factor on overall airplane reliabiliy."[3] Currently, the Air Force is spending 15% of its total R&D budget on avionics. Technological developments are proceeding so rapidly that the Air Force is "turning over" its avionics inventory every fifteen to twenty years. These technological developments have large impacts on system support

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[1]The F-18 and A-18 life cycle costs are based on 20 years, 1980-2000, McDonnell Aircraft Company briefing, August 1977.

[2]The F-16 life cycle costs are based on 15 years, 1977-1992, General Dynamics Fort Worth briefing, August 1977.

[3]*Air Force Magazine*, July 1977, p. 30.

costs as dramatic changes occur in avionics equipment characteristics and in maintenance concepts.

In summary, the avionics technology is changing rapidly making it extremely difficult for DoD to define with any precision early in system acquisition (DSARC 0 or I) the characteristics of avionics equipment that eventually will be installed on a fighter aircraft or the maintenance concepts to be applied to that equipment. On the other hand, these early decisions are extremely important because they will have a major impact on the final support costs to be incurred by the system when it becomes operational.

Several alternatives are available to the Secretary of Defense when addressing this problem. First, he may conclude that it is virtually impossible to estimate avionics support costs as early as DSARC 0 or I and either disregard support costs at these milestones or limit the analysis to broad total system estimates. This alternative has the disadvantage of offering no guidance to the system developers regarding the importance of support costs on avionics compared to performance, schedule or other cost variables. Another disadvantage is that alternative avionics suites cannot be assessed against each other for a specific aircraft or for different F-X aircraft proposals. SECDEF can emphasize in general terms the importance of cost minimization but this does not help the designer who must consider alternative ways for fulfilling the avionics functions on the aircraft.

Another alternative is to acquire data on the historical Service cost experience in supporting avionics equipment, then attempt to determine how these costs should change when the new aircraft enters the inventory. This alternative requires a reasonably accurate data base. It also requires a "crystal ball" analysis of current versus future technological state-of-the-art equipments, maintenance concepts, and the impact on

historical support costs of any forecast changes in equipment or maintenance concepts.

Since the SECDEF must consider possible future system support costs even when system characteristics are ill-defined, in subsequent chapters we will discuss the ways in which the Services and contractors treat the problem of estimating avionics support costs in the early stages of major system acquisition. It is useful to precede these Service and contractor discussions by a consideration of the most prominent conceptual problems associated with early component support costs estimates, particularly as they apply to avionics components.

1. System Characteristics Versus Maintenance Concepts

There is an interaction between system characteristics and maintenance concepts that tends to compound the problem of the cost analyst. First, it must be recognized that the characteristics of the avionics equipment have a major impact on the concepts that must be adopted by the Services to maintain that equipment. For example, relatively simple equipment should be repairable in the field whereas complex equipment can only be satisfactorily repaired at a depot or even in the manufacturer's facility. On the other hand, technological developments may simplify certain repair functions permitting more field maintenance of equipments that in the aggregate may be very complex. Therefore, it may be necessary to define fairly specifically the characteristics of some avionics equipment before the Service can resolve questions relating to maintenance concepts. These concepts can have a heavy impact on maintenance manpower and spares requirements.

On the other hand, maintenance concepts may dictate some of the requirements in avionics equipment components. War plans may require certain maintenance capabilities in field units and these, in turn, may have a major impact on how the avionics equipment must be designed.

Service statements of operational requirements (ORs and ROCs) may resolve the issue of system characteristics versus maintenance concepts. However, in the two dynamic areas of national defense needs and avionics technology changes, developments may occur through the acquisitiion cycle that require a reexamination of this interface. For example, miniaturization of electronics components offers significant opportunities for changes in concepts to perform the maintenance function more efficiently and effectively.

For this reason, support cost estimates made very early in the acquisition cycle, particularly if based on parametric cost estimating relationships using historical cost data, could prove to be quite inaccurate.[1]

2. Use of Historical Data as a Basis for Cost Estimating

Avionics support cost estimating methods are of several types. The first method referred to is an "engineering" or "bottoms-up" approach that examines the individual components in the avionics suite of an aircraft and attempts to calculate future support costs by estimating such factors as forecast reliability and maintainability of the individual items. Numbers of required spare parts and maintenance manhours can be computed. To these totals the analyst applies price list data on parts and labor rates per hour. By aggregating cost data it is possible to derive a support cost estimate for the full life cycle of an aircraft.[2]

Another major support cost estimating method is based on the use of a data base containing historical information on support costs of existing avionics equipment. The analyst

[1]The conceptual implications of using parametric regression techniques in a rapidly changing environment are addressed in Chapter IV.

[2]See the discussion of the Westinghouse EAR program in Chapter III.

attempts to find an aircraft with avionics equipment comparable to the equipment that may be installed on the new aircraft, and this equipment is used as a baseline system of reference. By analogy and scaling, usually based on judgment and using historical data on the baseline system, the analyst will attempt to put together a cost estimate for the support of the avionics equipment on the new aircraft.[1]

An approach that uses historical data in statistical techniques that permit quantatitive measures of uncertainty is the development of parametric cost estimating equations. For example, through regression analysis using historical data the analyst may find that avionics equipment weight seems to be a suitable independent variable in an equation to explain support costs for avionics equipment. Thus, given the probable weights of the avionics equipment in the new aircraft, the analyst simply uses the equation to compute the future support costs for that new equipment.[2]

There are at least three major problems associated with the use of historical data bases in developing estimates of future support costs for avionics equipment, and these are discussed below.

a. Data accuracy

It is readily agreed by experienced analysts that serious inaccuracies exist in Service data related to field maintenance actions and the costs of those actions. Differences in terminology between field and depot maintenance accounting systems and differences in equipment nomenclature introduce other potential accuracy, consistency, and comparability problems when data from the two types of systems are combined.

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[1]See the discussion of analogy estimating in Chapter III.

[2]See regression discussions in Chapters II and III.

A major problem in accounting for spare parts support is to identify the equipment on which a particular spare part shipped from the depot will be installed. This is especially important when attempting to use analogy for cost estimating since the baseline system costs should be complete and relatively accurate if they are to be used as a basis for projection of costs on the new system.

These are just a few of the problems relating to accuracy of historical data. These problems may be overcome by scientific sampling of data on field experience, by research in the field to adjust reported data that permits an analyst to, in effect, "build" a data base, and through other special actions. The difficulty is that these efforts can be extremely expensive and time-consuming and still may not yield accurate data. It must be recognized, however, that new DoD data management systems such as those developed under the OSD-directed Visibility and Management of Support Cost program (VAMOSC) offer hope for overcoming accuracy and consistency problems, thereby enhancing the opportunities to compare costs between and among systems.[1]

b. <u>Changing Institutions</u>

Any analysis using historical data must assume a certain amount of constancy in the institutions that have an impact on that data. For example, data on support costs of weapon systems during the Vietnam War would probably be of little value as an indicator of support costs in today's peacetime environment.

Reorganizations of operational forces or logistic support activities can affect significantly total support costs for

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[1]See Department of the Navy, Air Systems Command, *NALCOMIS-O&S/(VAMOSC-AIR) Maintenance Subsystem Report,* December 31, 1976 and *NALCOMIS-O&S (VAMOSC-AIR) Total Support System Report,* December 31, 1976. Also see Headquarters, U.S. Air Force, *Operating and Support Cost Estimating Reference (OSCER) Report, FY 76,* as of July 26, 1977.

avionics equipment. Even a shift in emphasis from organic to contract support or vice versa and the use of warranties on purchased equipment can invalidate cost estimates based on historical relationships because these historical relationships no longer apply.

Have skill levels changed under the All Volunteer Force concept? Have new system acquisition policies with requirements for more testing prior to procurement improved the quality and lowered support costs for new equipment? These are examples of institutional factors that could have important effects on maintenance support costs, thus invalidating a large body of historical information.

c. Technology

We have already discussed the way in which changing technology can cause historical cost data to be of limited value for predicting future support costs of new technology equipments. It follows that if technology is relatively stable for a given component of an aircraft or an avionics suite, historical data may be used to estimate future costs. Also, historical data may be adjusted to accomodate certain one-time technological changes. However, it is exceedingly difficult to develop proper adjustment factors for these data if technological changes are continuous and pervasive throughout the system. Experience dictates that avionics equipment undergoes this latter kind of technological change. When dealing with continuous change, the best approach is to develop some kind of technological change index number that can be applied to the final results of the calculations based on historical data. However, even to do this it is necessary that technology be changing at some constant rate over time. As a last resort, an analyst may adjust historically based support cost estimates by an equipment-by-equipment analysis of recent technological changes and, through judgment,

extrapolate the effects of these changes on support costs, but this is an unsystematic and highly subjective procedure that leads to uncertain results.

3. The "Fixed Cost" Problem

Most support cost estimating methods make no provision for the difference between fixed and variable costs; in fact, conceptually, they assume that all costs are variable. These methods generally attempt to develop a support cost per aircraft, per squadron, or per flying hour and the costs, therefore, vary in a strict linear fashion with the changes in the program variables.

This concept may be suitable if only gross cost estimates are desired and the decision-maker is willing to accept a wide margin of error, or if the changes in the program variables are relatively small. They may also be acceptable in trade-off analyses when the major difference between systems relate only to acquisition costs with their attendant impact on costs of spares.

In terms of the purpose of this study, the "fixed cost" problem may be most serious as related to field maintenance. It has been estimated that a maintenance technician works on maintenance tasks only about 40% of his time.[1] Presumably he has other responsibilities that consume the remainder of his time or he possesses a skill that must be available at the field unit even if that skill is used only 40% of the time.

The "fixed cost" problem is most serious when we are attempting to apply cost criteria in the selection of an alternative. We may find that savings indicated by a linear-based cost estimating method may be significantly overstated.

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[1]Based on Navy research and used by the Navy Air Development Center in estimating labor costs in the field.

Fixed costs in the real world envirnoment of employment of the aircraft system may reduce significantly or eliminate the presumed advantage of one system over another.

4. The Marginal Cost Concept

To this point we have been discussing cost methodologies that attempt to develop total life cycle support costs for fighter aircraft avionics systems. Application of marginal cost concepts must be identified as a potential solution to some costing problems. Regardless of the exact nature of a given avionics system, it can be assumed that all such systems will require spare and repair parts and field and depot maintenance support. Thus, it may be possible to consider the level of such support activities at a point in time as a "steady state" level of support. Then the analyst could attempt to develop support cost estimates on a marginal basis showing how the "steady state" costs would rise or decline with the introduction of the new aircraft.

This marginal cost approach, which is applied in many industrial environments, may be applicable in support cost estimating for avionics equipment.

5. Trade-Off Estimates Versus Point Estimates

Support cost estimates to validate specific point values of Service-contractor DCP estimates are different in character from estimates used to perform trade-offs between and among alternative component designs, configurations, and reliabililities. Ideally, an estimating technique should be able to produce cost estimates useful and accurate for both point and trade-off estimation, but practically there are major difficulties in combining both characteristics within a single technique.

Point validation estimates must be accurate in their absolute values because they are essentially estimating the

support costs as a fixed value at a distant point in time and these costs are the basis for affordability evaluations. In contrast, trade-off estimates must be consistent across different component designs and physical characteristics. That is, they must isolate the characteristics that distinguish one component design from another, but these characteristics need not be the same ones that contribute to fifteen year absolute life cycle cost values.

The implication of this difference between point and trade-off estimates is that it is possible that one methodological cost estimating approach would be appropriate to point estimates and another appropriate to trade-off estimates.

6. Coping With the Conceptual Problems

Throughout this paper we will be discussing support cost estimating methods and conceptual problems associated with those methods. Earlier we stated that DoDD 5000.1 prescribes that "...cost estimates shall not be finalized or considered firm prior to the Milestone II decision." This statement should not be construed to mean that no cost estimates need to be prepared prior to DSARC II.

Our conclusion after research on this study is that, in view of the importance of avionics support costs, estimates of these costs must be prepared prior to DSARC II. However, the OSD decision-maker must be willing to accept significant degrees of uncertainty in these estimates. Also, it may be desirable to use different methodologies at different decision points, so accounting-oriented efforts to have an audit trail from one estimate to the next may be inappropriate. More emphasis should be placed on reviewing the rationale and inputs for estimating methods than on precise comparisons of one estimate to the next. We believe, however, that from DSARC II on through the acquisition cycle, audit-trail type tracking is appropriate. These

comments on methodologies and the way to treat cost estimates apply equally to Service-provided estimates and independent estimates prepared at the OSD level.

Our research has persuaded us that based on the above statements regarding the use of estimates it is possible and, in fact, essential to produce avionics support cost estimates in the early stages of fighter aircraft acquisition programs. Given the acceptance of uncertainty in estimates, ways can be devised to cope with the conceptual problems in developing these estimates.

It cannot be emphasized too strongly that OSD cannot permit estimates prepared prior to DSARC II to become firm "bogeys" or targets for funding actions. They must be accepted as order of magnitude estimates so decisions can be made on the rough affordability of a new system. Attempts to apply audit-trail approaches to these estimates will be counter-productive. Analysts then would be forced to include factors for uncertain contingencies in their estimates or perhaps their estimates would be prepared and presented in a gamesmanship atmosphere rendering them of limited value.

In the final chapter of this paper we will present our recommendations on approaches to deal with the avionics support cost estimating problems, our conclusions regarding the conceptual problems, and our judgments of how cost estimates must be employed within the DoD major system acquisition review and decision-making environment.

G. PRIOR RESEARCH ON AVIONICS SUPPORT COST ESTIMATING

In our research we reviewed 150 reports and similar materials relating to the subject area of this study. We found 48 of these documents to be of sufficient relevance that we prepared descriptive summaries of them and have included these summaries in Appendix A of this paper.

Documents covering prior research may be grouped into the following categoires.

1. <u>Avionics - Institutional</u>

These publications establish a framework for understanding the multiple characteristics and uses of military electronics equipment. Publications in this group include coverage of avionics and are useful to give an understanding of problems associated with avionics support cost estimating. The most comprehensive study is *Electronics-X: A Study of Military Electronics With Particular Reference to Cost and Reliability*, Institute for Defense Analyses, January 1974.

2. <u>Avionics - Acquisition Policies and Cost Estimating Methods</u>

This group deals generally with the acquisition as opposed to operating phase of the avionics equipment life cycle. These research documents provide insights on hardware cost estimating methods that may be useful in considering the spare parts segment of the avionics support cost estimating process. An example of this research, which also provides considerable conceptual evaluations of the basic theoretical problems, is *Estimating Avionics Equipment Costs for Military Aircraft, J. Watson Noah Associates*, December 1974.

3. <u>Avionics - Support Cost Estimating Methods</u>

A few publications are available in this subject area. Usually this subject is treated in studies primarily directed toward acquisitions or life cycle cost estimating. None of this material was found to offer suitable, directly applicable, methods for estimating avionics support costs, particularly in early stages of hardware development. Work accomplished at the General Research Corporation has been prominent in this area, including *Cost Analysis of Avionics Equipment*, February 1974.

4. Cost/Technology Indices

A limited amount of information is available on prior research relating to cost/technology indices. The few studies available consider ways to modify acquisition cost estimates by factoring in the effects of changing technology on cost. We found limited prior research attempting to develop indices that might be used to adjust avionics support cost estimates to reflect changes in technology over time. A useful summary of previous work and a suggested alternative approach is provided in *Development of Avionics Cost Technology Indices*, Naval Air Development Center, April 1972.

5. Reducing or Controlling Avionics Costs

These studies address specific ways in which avionics acquisition and support costs may be reduced or controlled. In some instances they offer insights on the state-of-the-art in avionics cost estimating, for example the study *DoD Actions to Control Avionics Life-Cycle Costs*, RAND Corporation, May 1973. However, most of these studies are oriented more toward management techniques than cost estimating methods.

6. Statistical Techniques Used in Cost Estimating

A considerable body of literature exists on statistical techniques as applied to cost estimating. Some of this information is useful in considering what methods might be used for avionics support cost estimating. A good discussion and review of the estimating properties of various regression equation forms is presented in *Aircraft Operating and Support Cost Impacts of Support Concepts and Design Characteristics - Improved Regression Through Biased Estimators*, TRACOR, March 1976.

7. <u>Operations and Support Cost Estimating Methods</u>

These papers cover the entire field of O&S cost estimating. Some of them treat the general topics of O&S costs and others consider impacts of support concepts, reliability, maintainability and other factors that affect O&S costs. These publications provide useful information on support costs but do not address specifically the subject of this study. A typical equipment-level study of avionics is the *Research Study of Radar Reliability and Its Impact on Life Cycle Cost for the APQ-113, -114, -120, and -144 Radars*, General Electric, April 1973.

8. <u>Design to Cost</u>

A few studies and publications are available that address exclusively the topic of design to cost. These documents are of little use in this study except as general background on the DoD acquisition process. An example is provided by the *Joint Logistics Commanders Guide on Design to Cost*, Air Force Systems Command, Chief of Naval Material, and Army Materiel Command, January 1976.

9. <u>Life Cycle Costing</u>

A very considerable body of literature exists on life cycle costing. Included in this literature are descriptions of models, data sources, special studies, and guides for performing life cycle costing. None of these publications was found to provide specific tools or conceptual frameworks for dealing with the problem of avionics support cost estimating in the early stages of system acquisition. A primary resource document for an overview of life cycle costing methodology is *Life Cycle Cost Analysis Guide*, Joint Commander's Working Group on Life Cycle Cost, November 1975.

Chapter II

SERVICE SUPPORT COST ESTIMATING METHODOLOGIES FOR FIGHTER AIRCRAFT AVIONICS

A. INTRODUCTION

Current Air Force and Navy fighter aircraft avionics support cost estimating methodologies are similar in form but differ in the emphasis and applications they receive as employed by the two Services. Prior to source selection and DSARC II, both Services exercise total weapon system-level methodologies that do not address avionics support costs at the individual component equipment level. In the Air Force, an historical cost factor model estimates support costs for the airframe, propulsion system, and the total avionics suite on a proposed aircraft;[1] while in the Navy, a parametric regression model produces total aircraft estimates for several categories including depot maintenance component rework, which is primarily done on avionics equipments,[2] and replenishment spares.

For source selection and DSARC II, the Air Force uses both the total system cost factors model and a detailed equipment level logistic support cost model that provides cost estimates for avionics and other individual equipments in several cost categories, including initial and replenishment spares and base

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[1]The Cost Analysis Cost Estimating (CACE) model is in Air Force Regulation 173-10, *USAF Cost and Planning Factors*, and is discussed in part B, section 3 of this chapter.

[2]The regression equations are presented in the F-18 aircraft program DSARC II documentation, and discussed in part C, section 3 of this chapter. Other cost categories include enlisted maintenance personnel, depot maintenance airframe rework, depot engine rework, POL, and other consumables.

and depot maintenance.[1] The Navy continues to rely on its weapon system-level regression equations and introduces individual component level methodologies following the DSARC II milestone. These methodologies include an internal Navy cost tracking model[2] and a jointly developed Navy and prime airframe contractor detailed equipment level model.[3]

Several other models are applied by the Services to individual elements of support costs, but these models are not comprehesive support cost estimating methodologies that address at a minimum the costs of maintenance at all levels and spares and repair parts support.

This chapter examines these various methodologies and models in terms of their potential usefulness to OSD for providing avionics support cost estimating capabilities early in the acquisition cycle. The actual assessments of these methodologies and models are presented in Chapters IV and V. The emphasis in this chapter is on describing the specific models to reveal their structures and assumptions. The significance of the roles these models play in the Services is not a measure of the attention devoted to them in this chapter. As an example, the Air Force CACE historical factors model is a major Air Force tool for weapon system-level estimates, but it is treated relatively lightly in this chapter because its application potential for estimating avionics component support costs is limited. In contrast, the roughly equivalent Navy

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[1]The Air Force Logistics Command (AFLC) Logistics Support Cost (LSC) Model, discussed in part B, section 3 of this chapter.

[2]The cost tracking model as used by the Navy for the F-18 development program is solely intended as a baseline generator against which changes in component support costs can be monitored; it is not intended in any way as a generator of component support cost actuals. However, it offers a potential approach that could generate actual cost estimates. See part C, section 3 of this chapter.

[3]The F-18 McDonnell Douglas equipment level support cost model is discussed in part C, section 3 of this chapter.

regression weapon system-level model is treated in substantial detail, because it is the basis for a component level estimating technique that could be applied early in the acquisition cycle.

Data systems are also examined that currently provide inputs to the Service estimating models, and again the emphasis is on these systems' potentials for providing inputs to early acquisition cycle models useful at the OSD level.

With these perspectives in mind, we first examine the Air Force methodologies, policies, and data systems, and then we examine those of the Navy.

B. AIR FORCE METHODOLOGIES, POLICIES, AND DATA SYSTEMS

1. Introduction

Support costs for avionics equipment on new fighter aircraft are first estimated by the Air Force just prior to the full-scale engineering development decision milestone (DSARC II). Although these support cost estimates come relatively late in the acquisition cycle, this should not be interpreted as evidence that they cannot be made earlier. The discussions of support cost estimating methodologies presented in this section of the paper describe the current Air Force techniques. Because these descriptions are structured within the framework of current programs like the F-16 Air Combat Fighter (ACF), the descriptions necessarily relate to how and when cost estimates are currently produced. But the timing in the acquisition process of when equipment-level cost estimates first appear is a matter of policy, not necessity dictated by the lack of methodologies and techniques. We believe that many cost estimating techniques can be applied at any time during the acquisition process, and further that the applications of specific techniques discussed in this section can be implemented at any time given certain assumptions about the data that provide inputs into them. These assumptions are presented later in the discussion of data systems.

The major policies and procedures guiding the Air Force cost estimating efforts are the recently revised DoDDs 5000.1, 5000.2, and 4105.62, the source selection directive.

Based on these policies and procedures, the Air Force uses several specific cost estimating methodologies embodied in the following major cost estimating models and methods:

(1) AFLC Logistic Support Cost (LSC) model,
(2) Logistics Composite Model (LCOM),
(3) MOD-METRIC Model,
(4) Optimum Repair Level Analysis Model (ORLA),
(5) Parametric regression equations models.

The key data and management information systems that relate to avionics support costs include:

(1) Operating and Support Cost Estimating Reference (OSCER) System,
(2) Increase Reliability of Operational Systems (IROS) Data Management System (K051),
(3) Maintenance Actions, Manhours, and Aborts by Work Unit Code Reporting System (D056),
(4) Aerospace Vehicle Inventory, Status, and Utilization Reporting System (AVISURS) (G033),
(5) Aircraft Inertial Navigation System Performance, Test, and Diagnostic Analysis System (G078C),
(6) Actuarial Analysis Program (D057F),
(7) Economic Ordering Quantity Data Bank (D062),
(8) Depot Maintenance Industrial Fund Cost Accounting Production Report (H036B).

2. Policies and Procedures

Air Force policies and procedures for estimating avionics support costs on fighter aircraft are not explicitly differentiated from general cost estimating policies and procedures that the Air Force has established to comply with the DoD directives discussed in Chapter I.

The Secretary of Defense decision at DSARC 0 is based on documentation contained in the Mission Element Need Statement. The MENS does not normally contain cost estimates; however, cost data may be required of the Air Force if the mission need for a new system acquisition is identified in terms of a major cost saving advantage over an existing system. In this situation, cost estimates even at the DSARC 0 milestone decision would become relevant for Air Force action. Whether the cost estimates would be displayed at the two-digit work unit code level, called the "system level," or in greater detail at the LRU or SRU level, would depend on the specific mission need and cost saving opportunity. The possibility certainly exists that detailed cost estimates could be required at DSARC 0 for inclusion in a MENS documentation. At this time Air Force policy does not explicitly require cost estimates at DSARC 0, but, as will be explained later, parametric regression cost estimating equations, manpower simulations models, and the AFLC Logistic Support Cost Model could be used to provide DSARC 0 cost estimates.

At the end of the conceptual phase, when the Air Force wishes to secure SECDEF approval for system demonstration and validation, a draft Decision Coordinating Paper (DCP) is prepared which contains the System Project Office (SPO) cost estimates and an Independent Cost Analysis (ICA) is conducted. The DCP and the supporting ICA are forwarded to OSD as part of the input for the DSARC I milestone decision. The draft DCP contains the initial weapon system level cost of ownership estimates for the system under construction, and is based on the Cost Analysis Cost Estimating (CACE) Model discussed later in this paper. These estimates do not include support costs for avionics at the equipment level. The recurring investment and miscellaneous logistics costs calculated by the CACE model include common AGE replacement and spares, aviation fuel, base level maintenance material, depot level labor and material maintenance,

Class IV modifications and their initial spares, training munitions, replenishment spares, and vehicular equipment.

Accompanying the SPO estimates that go into the DCP are ICA estimates prepared by AFSC headquarters using the CACE model equations and factors. It is also in this conceptual phase draft DCP that the AFLC LSC model is identified as the basis for equipment level operating and support cost submissions by the potential contractors to the Air Force and intended for use in the source selection process. This identification of the LSC model as a source selection requirement placed on the contractor is the initial formal specification of an Air Force requirement for equipment-level support cost estimates. The LSC model will be run by the contractors prior to source selection, but its first official submittal to the Air Force comes at the time of the demonstration for the source selection decision. This submittal to the Air Force only comes as the process nears the source selection phase just prior to a SECDEF DSARC II full-scale development decision.

Following an affirmative SECDEF DSARC I (program validation and documentation) decision, the validation and demonstration phase of the acquisition process is entered. This phase culminates in the preparation of a DCP and an ICA upon which the source selection and the DSARC II full-scale development decision are based. For the SPO DCP estimates the parametric CACE model is used again to preserve consistency in comparing the DSARC II with the DSARC I cost estimates; in addition, the LSC model is exercised using test data to estimate reliability and maintainability characteristics of individual components. Initial and replenishment spares costs are developed using spares optimization models, and base level maintenance requirements are developed through the use of maintenance manpower simulation models. These techniques permit the Air Force to provide equipment level avionics support costs at the conclusion

of the validation-demonstration phase as part of the documentation for source selection and the full-scale development decision.

The ICA relies on parametric regression CACE model equations even at DSARC II, and where possible, checks equipment-level costs against system performance estimates, limited test data, specific design characteristics, and limited detail design and preliminary make or buy lists. Using these data, selected equipment acquisition costs can be estimated by hand. Some support costs can be estimated by using these equipment acquisition costs as independent variables in parametric equations.

Following the DSARC II decision, equipment-level avionics support costs are available throughout the remaining segments of the acquisition process.

Prior to DSARC II, all cost estimates are preliminary and flexible, but the estimates approved in the DSARC II decision become management values used by the Air Force and the SPO against which to measure contractor performance. The fact that the cost estimates are not binding until an affirmative DSARC II decision does not diminish the usefulness of pre-DSARC II cost estimates for avionics equipment at two-digit and five-digit WUC levels.

3. Cost Estimating Methods

a. Overview

The cost estimating methods discussed here include all the major methods touched on in the preceding discussion of policies and procedures, but only those methods that provide avionics equipment level O&S costs are described in detail. In addition, some recent exploratory work on avionics O&S cost estimating methods is discussed, particularly the activities monitored through the Air Force Avionics Laboratory (AFAL) at Wright-Patterson Air Force Base.

b. AFLC Logistic Support Cost (LSC) Model

(1) Basic Structure

The AFLC LSC model is the major Air Force cost estimating techinque that provides O&S estimates at the detailed equipment level, including avionics equipment. The LSC *User's Handbook*, August 1976, describes the model as an analytical accounting model. The analytical descriptor indicates that it yields specific point values instead of frequency distributions of ranges of values. The accounting descriptor indicates that it calculates costs for small detailed levels of equipment and aggregates them to produce values for the entire system of which the detailed equipments are the constituent parts.

The model contains ten basic equations, one for each of ten "logistic support" costs. The costs (equation names) and their single symbol identifiers are:

C_1 = cost of first line unit (FLU) spares
C_2 = cost of FLU on-equipment maintenance
C_3 = cost of FLU off-equipment maintenance
C_4 = cost of FLU inventory management
C_5 = cost of FLU support equipment
C_6 = cost of personnel training for FLU's
C_7 = cost of FLU management and technical data
C_8 = cost of facilities
C_9 = cost of fuel consumption
C_{10} = cost of spare engines.

The first three costs, C_1, C_2, and C_3 constitute support costs that are relevant for the task (DP&E-110) addressed in this paper. The equation structures for each of these costs are presented in the figures to follow. In addition, the equation structure for support equipment costs is also examined.

(2) Spares costs

Figure 1 displays the structure of the spares costs equation in the LSC model. The first two elements, C_{11} and C_{12}, compute initial spares costs at base and depot, respectively, while the third element computes replenishment spares. The quantities of initial spares are computed based on the peak level of program activity rather than an incremental build-up.

The critical term in the initial base pipeline equation (C_{11}) is STK_i, which is the number of spares of the i^{th} FLU required for each base to fill the base repair pipeline including a safety stock to prepare for random demand fluctuations. As seen in Figure 1, STK_i is based on the mean demand rate per base (λ_i), the weighted pipeline time (t_i), and expected backorders (EBO)--the established standard time for expected weapon system backorders. The details of each of these elements require substantial input data from both contractors and the Air Force. Since the C_{11} equation sums costs across all FLUs, this complex equation STK_i is calculated once for each FLU in the system. Detailed FLU input values such as MTBF, NRTS rates, the fraction of FLUs required in place, and the average number of hours to fault-isolate, remove, and replace each FLU are all required to calculate the STK_i base spares pipeline. Once STK_i is calculated for each FLU, it is multiplied times the initial provisioning FLU cost of each FLU, and these calculated costs are all summed to produce the initial base spares cost estimate, C_{11}.

The depot initial spares cost estimate, C_{12}, is less complex than for base spares but also requires specific FLU input data including MTBF, NRTS rates, and fraction of failed FLUs repaired in place, for each FLU. Based on these variables, the complex term in C_{12} calculates a quantity of initial depot spares for each FLU. These FLU quantities are multiplied times their respective initial provisioning costs and them summed to produce total depot initial spares cost.

The replenishment spares element, C_{13}, also requires specific support characteristic data for each FLU: MTBF, base condemnations, fraction of failed FLUs repaired in place, ratio of operating to flying hours, and number of like FLUs in the parent system. Again, the complex term calculates spares quantities and the quantities are multiplied times their acquisition prices and the total replenishment spares costs is calculated.

(3) <u>On-Equipment Maintenance Cost</u>

Figure 2 displays the structure of the on-equipment FLU maintenance cost equation, C_2, where it is composed of the manhour cost to perform flight-line maintenance on FLUs due to unscheduled failures (C_{21}), and the manhour cost to perform scheduled maintenance (C_{22}). As would be expected, the unscheduled on-equipment maintenance equation element requires detailed manhour data for each FLU, including the average manhours to fault-isolate, remove and repair each FLU, the on-time corrective maintenance manhours per FLU, and the in-place preparation and access manhours. Besides the manhour data by FLU, additional FLU level detail data is required in the forms of the fraction of failed FLUs repaired in place and MTBF.

The scheduled maintenance element, C_{22}, is not dependent on detailed FLU data. It is simply the total force flying hours divided by the flying hour interval between scheduled maintenance actions (scheduled periodic or phased inspections) for the aircraft multiplied times the base labor rate and the average manhours to perform a scheduled maintenance action.

(4) <u>Off-Equipment Maintenance Cost</u>

Figure 3 shows the complex structure of the off-equipment FLU maintenance cost equations. The C_{31} element calculates the number of failed removed FLUs subject to maintenance action.

1. C_1 = cost of FLU[1] spares = $C_{11} + C_{12} + C_{13}$

Where C_{11} = cost of initial base spares.

C_{12} = cost of initial depot spares.

C_{13} = cost of replenishment spares.

2. $C_{11} = \left[M \sum_{i=1}^{N} (STK_i)(UC_i) \right.$

- Initial provisioning FLU cost
- Number of bases
- Total number of FLU's in system

STK_i = Minimum number of spares of the ith FLU required for each base to fill the repair pipeline including a safety stock. → Based on

- EBO = expected backorders - number of
  existing at the lowest echelons
- λ_i = mean demand rate per base

  = $(PFFH)(QPA_i)(UF_i)(1\text{-}RIP_i)/M(MTBF_i$

- t_i = weighted pipeline time

  = $(RTS_i)(BRCT) + (NRTS_i)(OST)$

3. $C_{12} = \left[\sum_{i=1}^{N} \right. \dfrac{(PFFH)(QPA_i)(UF_i)(1\text{-}RIP_i)(NRTS_i)(DRCT)}{MTBF_i} \quad (UC_i)$

- Initial provisioning FLU cost
- Depot repair cycle time
- Not repairable this station
- Fraction of failed FLU's repaired in place[2]
- Mean time before failure
- Ratio of operating to flying hours
- Number of FLU's in parent system
- Peak force flying hours
- Total number of FLU's in system

4. $C_{13} = \left[\sum_{i=1}^{N} \right. \dfrac{(TTFH)(QPA_i)(UF_i)1\text{-}RIP_i)(COND_i)}{MTBF_i} \quad (UC_i)$

- Initial provisioning FLU cost
- Base condemnation proportion of failed FLU's
- Fraction of failed FLU's repaired in place[2]
- Ratio of operating to flying hours
- Mean time before failure
- Number of like FLU's in parent system
- Total force flying hours
- Total number of FLU's in system

[1] A First Line Unit (FLU) is the first level of assembly below the two-digit work unit code (WUC) equipment level that is carried as a line item of supply at base level. It is usually th
or sub-system in order to return the equipment to an operational condition. A lower level subassembly within a FLU, called a Shop Replaceable Unit (SRU), that is required or replaced

[2] The term RIP_i, repaired in place, is a number giving the fraction of failed FLU's repaired in place. The complete term $1\text{-}RIP_i$, is a number giving the fraction of failed FLU's not repa

Figure 1. SPARES COST EQUATION STRUCTURE IN THE AFLC LOGISTIC SUPPORT COST MODE

→ Based on →

- → EBO = expected backorders - number of unfilled demands existing at the lowest echelons at any point in time.
- → λ_i = mean demand rate per base

  = $(PFFH)(QPA_i)(UF_i)(1-RIP_i)/M(MTBF_i)$

  - $MTBF_i$ → Mean time (flying hours) before failure
  - M → Number of bases
  - RIP_i → Fraction of failed FLU's repaired in place[2]
  - UF_i → Ratio of operating to flying hours
  - QPA_i → Number of FLU's in parent system
  - PFFH → Peak force flying hours

- → t_i = weighted pipeline time

  = $(RTS_i)(BRCT) + (NRTS_i)(OST)$

  - OST → Order and shipping time in months
  - $NRTS_i$ → Not repairable this station
  - BRCT → Average base repair cycle in months
  - RTS_i → Average number of hours to fault isolate, remove and replace.

Where: $\lambda_i t_i$ = expected number of demands on supply for the ith FLU over its average base repair pipeline time.

Find: A minimum value of STK such that,

$$\sum_{x>STK_i} (x-STK_i)p(x\ \lambda_i t_i) \leq EBO$$

$x>STK_i$, and $p(x\ \lambda_i t_i)$ is a Poisson distribution of the probabilities of demand X given mean demand $\lambda_i t_i$.

red in place[2]

urs

m

failed FLU's

ed in place[2]

urs

system

at is carried as a line item of supply at base level. It is usually the highest level of assembly that is removed and replaced on the complete system
LU, called a Shop Replaceable Unit (SRU), that is required or replaced only at intermediate level shops is not defined as a FLU.

term $1-RIP_i$, is a number giving the fraction of failed FLU's not repaired in place.

AFLC LOGISTIC SUPPORT COST MODEL

1. C_2 = cost of on-equipment FLU[1] maintenance = $C_{21} + C_{22}$

Where: C_{21} = manhour cost to perform on-equipment (flight line) maintenanc
system life.

C_{22} = manhour cost to perform scheduled maintenance on the complete

2. $$C_{21} = \left[\sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} \right. [PAMH_i + (RIP_i)(IMH_i) + (1-RIP_i)(RMH_i)](BLR)$$

- BLR → Ba
- RMH_i → Average ma
- $1-RIP_i$ → Fraction of faile
- IMH_i → On-time corrective maintena
- RIP_i → Fraction of failed FLU's repaired
- $PAMH_i$ → In-place preparation and access manhours
- UF_i → Ratio of operating to flying hours
- QPA_i → Number of like FLU's in parent system
- $MTBF_i$ → Mean time between failure
- TFFH → Total force flying hours
- N → Total number of FLU's in system

3. $$C_{22} = \left[\frac{TFFH}{SMI} \right. (SMH)(BLR)$$

- BLR → Base labor rate
- SMH → Average manhours to perform scheduled periodic or p
- SMI → Flying hour interval between scheduled periodic or
- TFFH → Total force flying hours

[1]A First Line Unit (FLU) is the first level of assembly below the two-digit Work Unit Code (WU
at base level. It is usually the highest level of assembly that is removed and replaced on t
equipment to an operational condition. A lower level sub-assembly within a FLU, called a Sho
at intermediate level shops is not defined as a FLU.

[2]The term RIP_i, repaired in place, is a number giving the fraction of failed FLU's repaired in
fraction of failed FLU's not repaired in place.

[3]The variables in this bracketed term constitute the weighted average on-equipment maintenance
and access time and either in-place repair or removal and replacement.

Figure 2. ON-EQUIPMENT MAINTENANCE COST EQUATION IN THE AFLC LOGISTIC SUPP

nce = $C_{21} + C_{22}$

n-equipment (flight line) maintenance on FLU's due to unscheduled failures over the

cheduled maintenance on the complete system over the life cycle.

$RIP_i)(IMH_i) + (1-RIP_i)(RMH_i)](BLR)$

→ Base labor rate

→ Average manhours to fault isolate, remove and repair

→ Fraction of failed FLU's repaired in place[2]

→ On-time corrective maintenance manhours

→ Fraction of failed FLU's repaired in place

lace preparation and access manhours

operating to flying hours

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ber of FLU's in system

s to perform scheduled periodic or phased inspection

erval between scheduled periodic or phased inspection

ing hours

bly below the two-digit Work Unit Code (WUC) equipment level that is carried as a line item of supply assembly that is removed and replaced on the complete system or sub-system in order to return the el sub-assembly within a FLU, called a Shop Replaceable Unit (SRU), that is repaired or replaced only U.

ng the fraction of failed FLU's repaired in place. The complete term $1-RIP_i$, is a number giving the

weighted average on-equipment maintenance manhours per failure of the i^{th} FLU including preparation al and replacement.

EQUATION IN THE AFLC LOGISTIC SUPPORT COST MODEL

1. C_3 = cost of off-equipment FLU[1] maintenance = $C_{31}\left\{C_{32} + C_{33} + C_{34} + C_{35}\right\}$ = labor and material cost to perform off-equipment maintenance on failed, removed FLU's in base or depot repair facilities.

Where: C_{31} = number of failed removed FLU's subjected to maintenance action

C_{32} = cost of failure verification manhours

C_{33} = intermediate maintenance repair cost based on direct repair manhours and implied repair disposition cost to stock and repair lower indenture components and assemblies

C_{34} = depot maintenance repair cost based on direct repair manhours and implied repair disposition cost to stock and repair lower indenture components and assemblies

C_{35} = transportation cost for NRTS FLU's and condemnation replacements

2. $C_{31} = \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)}{MTBF_i}$

- RIP_i → Fraction of failed FLU's repaired in place[2]
- UF_i → Ratio of operating to flying hours
- $MTBF_i$ → Mean time between failure
- QPA_i → Number of like FLU's in parent system
- $TFFH$ → Total force flying hours
- N → Total number of FLU's in system

3. $C_{32} = (BCMH_i)(BLR)$

- BLR → Base labor rate
- $BCMH_i$ → Average manhours to perform shop bench check, screening and fault verification

4. $C_{33} = RTS_i[(BMH_i)(BLR+BMR) + (BMC_i)(UC_i)]$

- UC_i → Initial provisioning FLU cost
- BMC_i → Implied repair disposition cost to stock and repair lower indenture components and assemblies as a proportion of UC_i[3]
- BMR → Base consumable material consumption rate
- BLR → Base labor rate
- BMH_i → Intermediate maintenance average manhours[4]
- RTS_i → Fraction of removed FLU's repaired at base level

5. $C_{34} = NRTS_i[(DMH_i)(DLR+DMR) + (DMC_i)(UC_i)]$

- UC_i → Initial provisioning FLU cost
- DMC_i → Implicit labor, material, and stockage cost for lower indenture components and assemblies as a proportion of UC_i[5]
- DMR → Depot consumable material consumption rate
- DLR → Depot labor rate
- DMH_i → Depot maintenance average manours[4]
- $NRTS_i$ → Not repairable this station

6. $C_{35} = [2(NRTS_i) + COND_i][(PSC)(1-OS) + (PSO)(OS)]1.35W_i$

- W_i → FLU weight in pounds
- 1.35 → Ratio of packed to unpacked weight
- OS → Proportion of total force overseas

$i=1$

- Fraction of failed FLU's repaired in place[2]
- Ratio of operating to flying hours
- Mean time between failure
- Number of like FLU's in parent system
- Total force flying hours
- Total number of FLU's in system

3. $C_{32} = (BCMH_i)(BLR)$

- Base labor rate
- Average manhours to perform shop bench check, screening and fault verification

4. $C_{33} = RTS_i[(BMH_i)(BLR+DMR) + (BMC_i)(UC_i)]$

- Initial provisioning FLU cost
- Implied repair disposition cost to stock and repair lower indenture components and assemblies as a proportion of UC_i[3]
- Base consumable material consumption rate
- Base labor rate
- Intermediate maintenance average manhours[4]
- Fraction of removed FLU's repaired at base level

5. $C_{34} = NRTS_i[(DMH_i)(DLR+DMR) + (DMC_i)(UC_i)]$

- Initial provisioning FLU cost
- Implicit labor, material, and stockage cost for lower indenture components and assemblies as a proportion of UC_i[5]
- Depot consumable material consumption rate
- Depot labor rate
- Depot maintenance average manours[4]
- Not repairable this station

6. $C_{35} = [2(NRTS_i) + COND_i][(PSC)(1-OS) + (PSO)(OS)]1.35W_i$

- FLU weight in pounds
- Ratio of packed to unpacked weight
- Proportion of total force overseas
- Overseas packing and shipping cost
- Proportion of total force overseas[6]
- CONUS packing and shipping cost
- Base condemnation proportion of removed FLU's
- Not repairable this station

[1]A First Line Unit (FLU) is the first level of assembly below the two-digit Work Unit Code (WUC) equipment level that is carried as a line item of supply at base level. It is usually the highest level of assembly that is removed and replaced on the complete system or sub-system in order to return the equipment to an operational condition. A lower level sub-assembly within a FLU, called a Shop Replaceable Unit (SRU), that is repaired or replaced only at intermediate level shops is not defined as a FLU.

[2]The term RIP_i, repaired in place, is a number giving the fraction of failed FLU's repaired in place. The complete term $1\text{-}RIP_i$ is a number giving the fraction of failed FLU's not repaired in place.

[3]This is the average cost per failure for a FLU repaired at base level for the stockage and repair of lower level assemblies expressed as a fraction of FLU unit cost. This amounts to implicit costs for labor, material and stockage of lower indenture repairable components within the FLU, such as shop replacable units (SRU's).

[4]Average manhours to perform maintenance on a removed FLU including fault isolation, repair, and verification.

[5]This is the average cost per failure for a FLU repaired at depot, for stockage and repair of lower level assemblies expressed as a fraction of FLU unit cost. It amounts to implicit costs for labor, material, and stockage of SRU's.

[6]The term OS is proportion of total force overseas, so the term 1-OS represents total force not overseas.

Figure 3. OFF-EQUIPMENT MAINTENANCE COST EQUATION IN THE AFLC LOGISTIC SUPPORT COST MODEL

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THIS PAPER REPORTS ON RESEARCH TO DETERMINE THE FEASIBILITY OF DEVELOPING METHODS TO ESTIMATE, EARLY IN THE SYSTEM ACQUISITION CYCLE, THE POTENTIAL SUPPORT COST INPUTS OF ALTERNATIVE AVIONICS COMPONENTS ENVISIONED FOR AIR FORCE AND NAVY FIGHTER AIRCRAFT. SUPPORT COSTS ARE DEFINED AS THOSE COSTS INCURRED AT THE ORGANIZATIONAL, INTERMEDIATE AND DEPOT LEVELS TO MAINTAIN AVIONICS EQUIPMENT AND THE COSTS OF AVIONICS SPARES AND REPAIR PARTS SUPPORT. THE RESULTS OF THE STUDY ARE PRESENTED IN TWO VOLUMES. VOLUME I REVIEWS AND EVALUATES CURRENT METHODS USED IN INDUSTRY AND IN THE AIR FORCE AND NAVY TO ESTIMATE THESE AVIONICS SUPPORT COSTS; REVIEWS AND EVALUATES RELEVANT INDUSTRY AND DEFENSE STUDIES; REVIEWS INDUSTRY AND DOD DATA AND MANAGEMENT SYSTEMS THAT COULD PROVIDE DATA NEEDED FOR AVIONICS SUPPORT COST ESTIMATING TECHNIQUES; DISCUSSES THE FEASIBILITY OF DEVELOPING SUITABLE ESTIMATING TECHNIQUES; AND PRESENTS RECOMMENDATIONS ON THE BEST METHODS TO FOLLOW IN DEALING WITH THIS COST ESTIMATION PROBLEM AT DSARC O, I, AND II. THE PAPER PROVIDES A COMPREHENSIVE REVIEW OF THE DSARC PROCESS. IT DISCUSSES MAJOR CONCEPTUAL PROBLEMS IN DEVELOPING ESTIMATES OF FUTURE SUPPORT COSTS FOR EQUIPMENT STILL IN THE EARLY DEVELOPMENT STAGES. FINALLY, THE PAPER CONCLUDES THAT IS FEASIBLE AND DESIRABLE TO PREPARE THESE ESTIMATES FOR AVIONICS SUPPORT COSTS. THE SPECIFIC METHOD TO BE ADOPTED DEPENDS ON THE AMOUNT OF RESOURCES OSD WISHES TO DEVOTE TO THIS EFFORT.
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This is multiplied by appropriate calculated costs of failure verification, intermediate and depot repair costs, and transportation costs for NRTS FLUs and condemnation replacements. The maintenance sequence built into this equation is that all failed FLUs are first bench-checked to verify failure and then either repaired at the base intermediate maintenance shop (the RTS term in element C_{33}), returned to the depot for repair (the NRTS rate in element C_{34}), or condemned (the COND term in element C_{35}). The cost of failure verification results from manhours expended, represented by average manhours to perform shop bench check, screening and fault verification (BCMH in element C_{32}), and this is a contractor-furnished input variable for each FLU. The cost to repair a FLU results from direct repair manhours per FLU at the intermediate (term BMH in element C_{33}) and depot (term DMH in element C_{34}) levels, plus the implicit repair disposition cost to stock and repair lower indenture components and assemblies at the intermediate (term BMC in element C_{33}) and depot (term DMC in element C_{34}) levels. This implicit repair cost is for lower level assemblies such as shop replaceable units (SRUs) needed to repair FLUs.

(5) Support Equipment Cost

Figure 4 displays the structure of the cost of FLU support equipment, and this is the most complex of all the LSC model equations. The heart of the equation is elements C_{511}, C_{512}, and C_{514}. These elements calculate values that amount to a basic queing theory equation, where the number of pieces of support equipment necessary to support an anticipated workload is calculated as a function of the workload arrival rate (C_{511}), the service rate of an item of support equipment at the base (C_{512}) and depot (C_{514}) levels, and the base (term BUR) and depot (DUR) utilization rates. Given the calculations of the minimum necessary support equipment for each FLU, the equipment quantity is multiplied times the per unit acquisition and

support costs to yield total life cycle costs of support equipment used to repair FLUs.

(6) LSC Variables

The LSC model is often cited as being complex and requiring many data outputs. These comments are usually offered as evidence why the model equations can only be used once the weapon system has been precisely defined at least down to FLU level. There are ninety-five separate input vaiables provided at different levels of detail by both the government and the contractor. Figure 5 shows these input variables for the weapon system level, the propulsion system level, and the support equipment level. Figure 6 shows these variables for the system level (two-digit work unit code level) and the FLU level. Each of the system level variables is provided for each two-digit WUC piece of equipment; each FLU variable for each FLU; and most support equipment variables for each piece of support equipment. Hundreds, perhaps thousands of separate values of variables are required to operate the LSC model equations at their designed levels of detail.

In addition to being used by the SPO for DCP cost estimates, the LSC model equations have been adapted for use in the ICA at the DSARC II and III milestones for the F-16 ACF, and by the F-16 SPO to compute a set of target logistic support costs (TLSCs) by LRU. TLSC reflects conditions at the time of the 3500-flight-hour test. These TLSCs permit quarterly tracking of the high-cost FLU's to direct management attention to those that show substantial or sudden cost growth trends.[1] These multiple uses of the LSC model by the Air Force are evidence of its operational application as an equipment-level support cost model.

[1] *F-16 Logistic Support Cost Status Report* (UL 76 AQ), CDRL Sequence No. A017, March 11, 1977.

1. C_5 = Cost of support equipment used to repair FLU's = $C_{51} + C_{52}$

Where: C_{51} = Cost to acquire and maintain new depot and base peculiar shop FLU repair support equipment.

C_{52} = Cost to acquire and maintain new peculiar support equipment not directly workload-related and common support equipment procured in additional quantities.

2. $$C_{51} = C_{511} \sum_{i=1}^{K} \left\{ C_{512}\, C_{513} + C_{514}\, C_{515} \right\}$$

Where: C_{511} = Arrival rate of workload at base and depot shops for the ith FLU.
C_{512} = The service rate of the jth item of base shop support equipment used to repair FLU's.
C_{513} = Acquisition and operating costs of the jth item of base shop support equipment.
C_{514} = The service rate of the jth item of depot shop support equipment used to repair FLU's.
C_{515} = Acquisition and operating costs of the jth item of depot shop support equipment.

Elements C_{511}, C_{512}, and C_{514} derive from a basic queing theory equation designed to calculate the minimum number of pieces of support equipment required to service an anticipated workload. The queing equation is $\rho = \frac{\lambda}{n\mu}$, where rho($\rho$) is the combined utilization rate of the items of support equipment, lambda (λ) is the anticipated workload to be serviced by the equipment, n is the number of items of support equipment, and mu (μ) is the service rate of one item of support equipment. Rearrangement of the equation places n, the minimum quantity of required support equipment, as dependent on the other variables, $n = \frac{\lambda}{\rho\mu}$.

3. $$C_{511} = \left[\sum_{i=1}^{N} \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)}{MTBF_i} \right]$$

- PFFH: Peak force flying hours.
- QPA_i: Number of like FLU's in parent system.
- UF_i: Ratio of operating to flying hours.
- RIP_i: Fraction of failed LRU's repaired in place.[2]
- $MTBF_i$: Mean time between failure
- N: Total number of FLU's in system.

This term is the anticipated LRU workload and corresponds to lambda (λ) in the queing equation.

4. $$C_{512} = \frac{(BMH_i + BCMH_i)(RTS_i)}{(BUR_j)(BAA)(1-DOWN_j)}$$

- BMH_i: Intermediate maintenance average manhours.
- $BCMH_i$: Average bench check, screen, fault verify manhours.
- RTS_i: Fraction of removed FLU's repaired at base level.
- $DOWN_j$: Maintenance and calibration downtime proportion.
- BAA: Available base shop manhours/man/month.
- BUR_j: Base utilization rate for all equipment items.

This term is the service rate of an item of base shop support equipment, and it corresponds to the rho(ρ) in the queing equation. The summation sign with a range j=1 to k that appears before the expression containing C_{512} (see item 2 above) indicates that the equation is processed for each LRU, with LRU-peculiar data entered as values of the variables BMH, BCMH, RTS, and DOWN.

5. $$C_{513} = \left[1 + (PIUP)(COB_j)\right] CAB_j$$

- CAB_j: Base shop peculiar support equipment cost.
- COB_j: Annual cost to operate and maintain a unit of support equipment at base level as a fraction of unit cost CAB.
- PIUP: Program inventory usage period.

6. $$C_{514} = \frac{(DMH_i)(NRTS_i)}{(DUR_j)(DAA)(1-DOWN_j)}$$

- DMH_i: Depot maintenance average manhours.
- $NRTS_i$: Not repairable this station.
- $DOWN_j$: Maintenance and calibration downtime proportion.
- DAA: Available depot manhours/man/month.
- DUR_j: Depot utilization rate for all equipment items.

This term is the service rate of an item of depot support equipment, and it corresponds to mu (μ) in the queing equation. The summation sign with range j=1 to K indicates that the equation is processed for K LRU's.

7. $$C_{515} = \left[1 + (PIUP)(COD_j)\right] CAD_j$$

- CAD_j: Depot peculiar support equipment cost.
- COD_j: Annual cost to operate and maintain a unit of support equipment at depot level as a fraction of unit cost CAD.
- PIUP: Program inventory usage period.

8. $$C_{52} = \left[1 + 0.1(PIUP)\right] \left[DCA + DPA + M(BCA + BPA + FLA)\right] + CS + IH$$

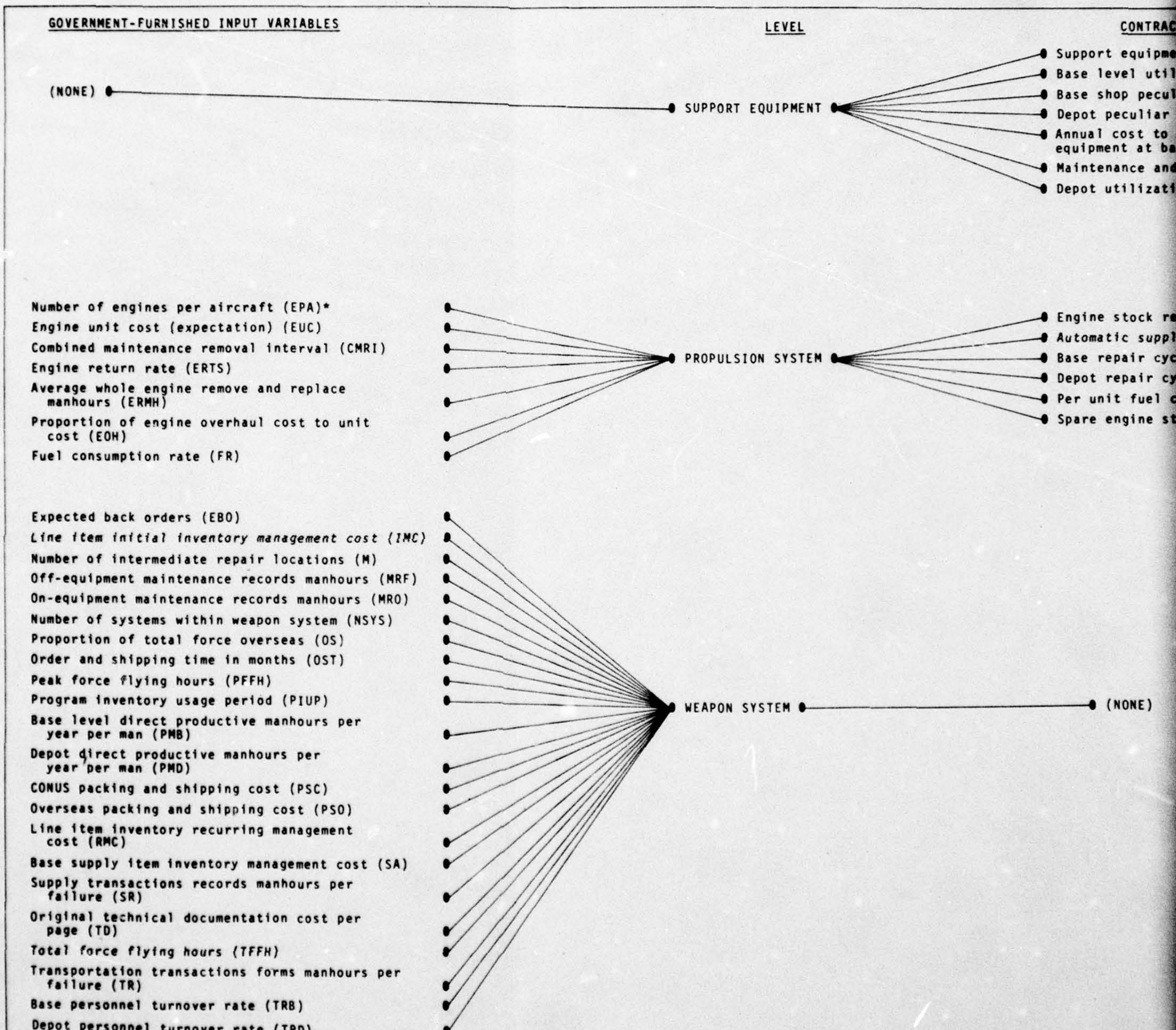
- IH: Existing automatic test equipment interconnecting hardware cost.
- CS: Existing automatic test equipment software cost.
- FLA: Peculiar flight-line support equipment cost per base.
- BPA: Base peculiar shop support equipment cost per base.
- BCA: Cost of additional common base shop support equipment per base.
- M: Number of intermediate repair locations.
- DPA: Depot peculiar support equipment cost.
- DCA: Additional common depot support equipment cost
- PIUP: Program inventory usage period.
- 0.1: Constant percentage of acquisition cost.[3]

[1]A First Line Unit (FLU) is the first level of assembly below the two-digit Work Unit Code (WUC) equipment level that is carried as a line item of supply at base level. It is usually the highest level of assembly that is removed and replaced on the complete system or sub-system in order to return the equipment to an operational condition. A lower level sub-assembly within a FLU, called a Shop Replaceable Unit (SRU), that is repaired or replaced only at intermediate level shops is not defined as a FLU.

[2]The term RIP_i, repaired in place, is a number giving the fraction of failed FLU's repaired in place. The complete term $1-RIP_i$ is a number giving the fraction of failed FLU's not repaired in place.

[3]This is the constant annual cost to operate and maintain support equipment as a fraction of the various unit costs in the equation.

Figure 4. COST OF SUPPORT EQUIPMENT EQUATION STRUCTURE IN AFLC LOGISTIC SUPPORT COST MODEL

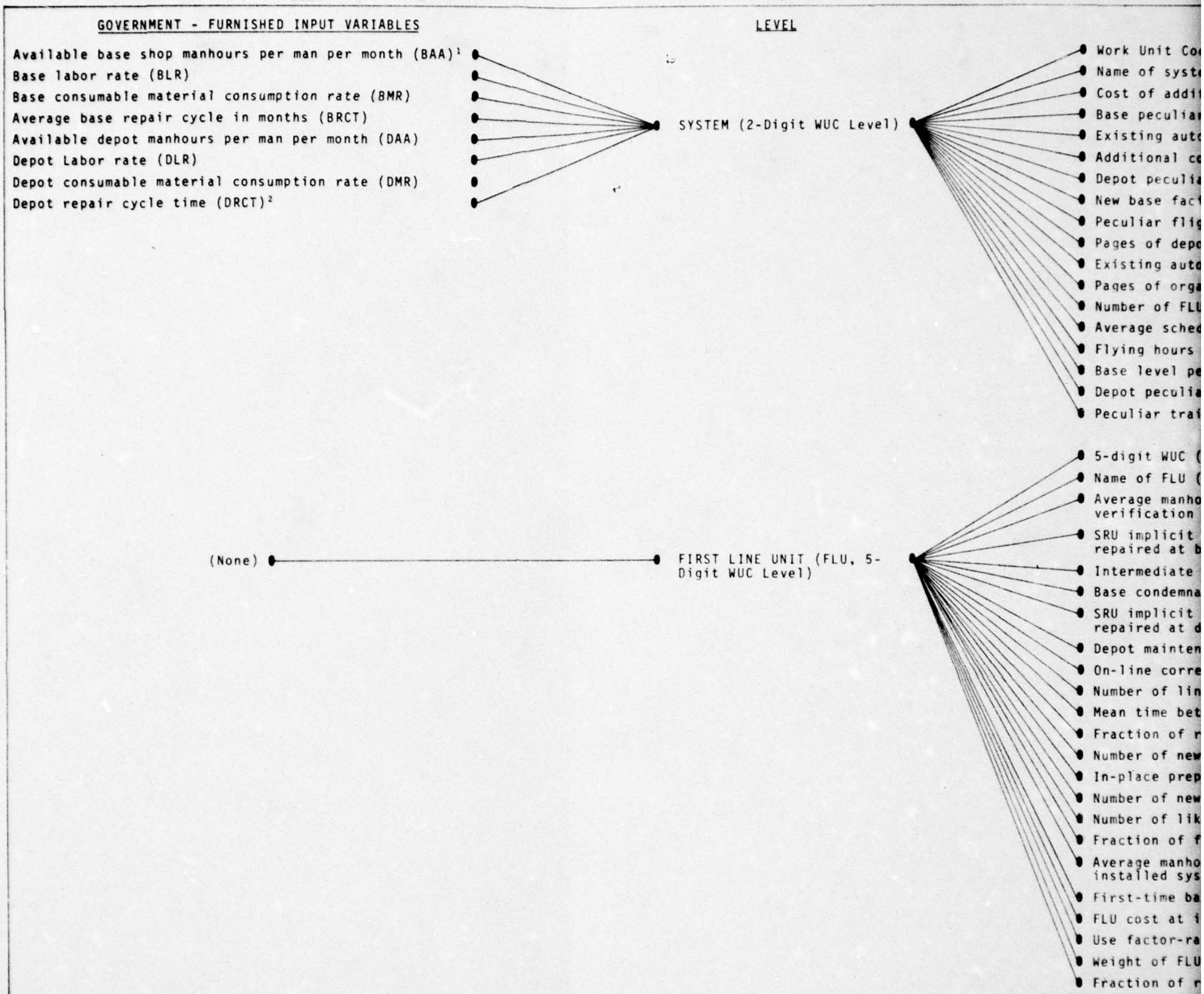


*Acronyms in parenthesis following each variable are those used in the LSC model.

Figure 5. AFLC LOGISTIC SUPPORT COST (LSC) MODEL INPUT DATA VARIABLES AT SUPPO PROPULSION, AND WEAPON SYSTEM LEVELS

LEVEL	CONTRACTOR-FURNISHED INPUT VARIABLES
SUPPORT EQUIPMENT	Support equipment identification, up to 20 characters (XSE)*
	Base level utilization rate for all items of equipment (BUR)
	Base shop peculiar support equipment cost (CAB)
	Depot peculiar support equipment cost (CAD)
	Annual cost to operate and maintain a unit of support equipment at base level as a fraction of unit cost (COB)
	Maintenance and calibration downtime proportion (DOWN)
	Depot utilization rate for all items of equipment (DUR)
PROPULSION SYSTEM	Engine stock replacement confidence factor (CONF)
	Automatic supply and buildup time in months (ARBUT)
	Base repair cycle in months (BP)
	Depot repair cycle in months (DP)
	Per unit fuel cost (FC)
	Spare engine stockage locations (LS)
WEAPON SYSTEM	(NONE)

LSC) MODEL INPUT DATA VARIABLES AT SUPPORT EQUIPMENT,
M LEVELS



[1]Acronyms in parenthesis following each variable are those used in the LSC model.

[2]This is a weighted average in months - the elapsed time for a NRTS item from removal of the failed item until it is returned to depot level serviceable stock. This incl the shop flow time within the specialized repair activity required to repair the item. For CONUS contractual repair the variable acronym changes to DRCTC, and for over

[3]This is the total cost of peculiar flight-line support equipment and additional items of common flight-line support equipment per base required for the system.

[4]This is the average cost per failure for a FLU repaired at base level for the stockage and repair of lower level assemblies expressed as a fraction of FLU unit cost. Th indenture repairable components within the FLU, such as shop replacable units (SRU's).

[5]Average manhours to perform maintenance on a removed FLU including fault isolation, repair, and verification.

[6]This is the average cost per failure for the stockage and repair of lower level assemblies used to repair failed FLU's at the depot. The cost is expressed as a fractio amounts to implicit costs for labor, material, and stockage of lower indenture repairable components within the FLU, components such as SRU's.

[7]Number of parts already stock-numbered (standard parts) in the FLU which bases will manage for the first time when the system is deployed.

Figure 6. AFLC LOGISTIC SUPPORT COST (LSC) MODEL INPUT DATA VARIABLES AT TWO-DIG CODE (WUC) LEVELS

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AD-A054 016 INSTITUTE FOR DEFENSE ANALYSES ARLINGTON VA COST ANAL--ETC F/G 15/5
THE FEASIBILITY OF ESTIMATING AVIONICS SUPPORT COSTS EARLY IN T--ETC(U)
SEP 77 J D MORGAN, A B FULLER DAHC15-73C-0200
UNCLASSIFIED P-1292-VOL-1 IDA/HQ-77-19730 NL

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LEVEL	CONTRACTOR - FURNISHED INPUT VARIABLES
SYSTEM (2-Digit WUC Level)	Work Unit Code (XSYS)[1]
	Name of system (SYSNOUN)
	Cost of additional common base shop support equipment per base (BCA)
	Base peculiar shop support equipment cost per base (BPA)
	Existing automatic test equipment software cost (CS)
	Additional common depot support equipment cost (DCA)
	Depot peculiar support equipment cost (DPA)
	New base facilities cost (FD)
	Peculiar flight-line support equipment cost per base (FLA)[3]
	Pages of depot technical orders and special repair instructions (H)
	Existing automatic equipment interconnecting hardware cost (IH)
	Pages of organization and intermediate technical orders (JJ)
	Number of FLU's in the system (N)
	Average scheduled periodic or phased inspection manhours (SMH)
	Flying hours between scheduled periodic or phased inspections (SMI)
	Base level peculiar training cost per man (TCB)
	Depot peculiar training cost per man (TCD)
	Peculiar training equipment cost (TE)
FIRST LINE UNIT (FLU, 5-Digit WUC Level)	5-digit WUC (XFLU)
	Name of FLU (FLUNOUN)
	Average manhours to perform shop bench check, screening, and fault verification (BCMH)
	SRU implicit labor, material and stockage cost per failure for FLU repaired at base (BMC)[4]
	Intermediate maintenance average manhours (BMH)[5]
	Base condemnation proportion of removed FLU's (COND)
	SRU implicit labor, material and stockage cost per failure for FLU[6] repaired at depot (DMC)
	Depot maintenance average manhours (DMH)[5]
	On-line corrective maintenance manhours without removal (IMH)
	Number of line items of peculiar shop support equipment (K)
	Mean time between failure (MTBF)
	Fraction of removed FLU's returned to depot (NRTS)
	Number of new P-coded repairable assemblies in FLU (PA)
	In-place preparation and access manhours (PAMH)
	Number of new P-coded consumables within FLU (PP)
	Number of like FLU's in parent system (QPA)
	Fraction of failed FLU's repaired in-place (RIP)
	Average manhours to fault isolate, remove and replace FLU on installed system (RMH)
	First-time base-managed standard parts in FLU (SP)[7]
	FLU cost at initial provisioning (UC)
	Use factor-ratio of operating to flying hours (UF)
	Weight of FLU in pounds (W)
	Fraction of removed FLU's repaired at base level (RTS)

failed item until it is returned to depot level serviceable stock. This includes the time required for base-to-depot transportation and handling and CONUS contractual repair the variable acronym changes to DRCTC, and for overseas contractual repair it changes to DRCTC.

mon flight-line support equipment per base required for the system.

epair of lower level assemblies expressed as a fraction of FLU unit cost. This amounts to implicit costs for labor, material and stockage of lower

and verification.

sed to repair failed FLU's at the depot. The cost is expressed as a fraction of FLU unit cost. This
mponents within the FLU, components such as SRU's.

or the first time when the system is deployed.

ODEL INPUT DATA VARIABLES AT TWO-DIGIT AND FIVE-DIGIT WORK UNIT

2

c. Logistics Composite Model (LCOM)

(1) Overview

The LCOM is a simulation model that provides estimates of the maintenance manpower requirements of a weapon system under development. Currently it is exercised for the DSARC II full-scale development decision. The model simulates flying a given set of aircraft and maintaining these aircraft. Its most important inputs include extensive data on the aircraft hardware including avionics equipment at the FLU level, and the operational scenario projected for the new weapon system.

(2) Comparability Analyses

The comparability analyses that are conducted on specific pieces of equipment are the most important elements of the LCOM approach applicable to the estimation of support costs for avionics equipment. These analyses are conducted by engineers and logistics experts, whose qualitative expert judgments are explicitly brought into the analyses. In these analyses an existing piece of equipment analogous to the proposed new piece of equipment is selected, the logistics characteristics of the analogous piece of equipment are identified, and then the analyst adjusts these characteristics to be consistent with the predicted characteristics of the new piece of equipment. Usually this is an upgrading of a logistics characteristic such as MTBF. A sample comparability worksheet is provided in Appendix C.

This comparability analyses approach is critical for several reasons. First, it provides the Air Force an opportunity to introduce into its manpower estimation models some of the same kinds of expert engineering judgments included in the engineering bottoms-up cost estimating approaches used by commercial avionics equipment producers. There is wide general agreement in the defense community that engineering bottoms-up approaches provide the most reliable cost estimates, with other things

such as maintenance concepts, operating scenarios, and the like held constant. If this general agreemnt about engineering cost estimates is correct, then the comparability analysis approach of LCOM introduces this element of accuracy into manpower estimating at the equipment level in the Air Force.

A second significance of the comparability approach is that it is possible to pursue it internally within the Air Force, thereby providing an independent engineering input into Air Force manpower estimates, independent of the avionics contractors.

The extensive data include the construction of "task networks" which constitute the LCOM model's primary data base. These task networks are sequences of maintenance actions resulting from sorties, inspection requirements, and component failures. Real data are structured from the AFM 66-1 maintenance data collection (MDC) system, collected from the AFLC DO 56 reporting system and the GO 33B-NWIA summary of aircraft sorties and flying hours from the AFM 65-110 reporting system. These specific systems are discussed later in the data systems section. The result is to take recorded maintenance actions on current systems and to translate them into maintenance frequencies and probabilities per flight. These task data outputs show average elapsed time, crew sizes, and mean sorties between maintenance actions. Shop work data also show the proportions of bench check okay and NRTS. These data are all available for the LCOM by WUC, Air Force Speciality Code (AFSC) (work center), and type of maintenance action. The data may be shown at the five-digit WUC level, usually identified as the line replaceable unit (LRU) level.[1]

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[1]Major D.C. Tetmeyer, S.R. Nichols, R.N. Deem, *Simulating Maintenance Manning for New Weapon Systems: Maintenance Data Analysis Programs*, Wright-Patterson AFB, Air Force Human Resources Laboratory, ASD, May 1976.

The actual MDC data provide baselines for existing pieces of equipment including avionics at the five-digit WUC level. The analyst then creates characteristics for new equipment on a proposed system by "building" on the baseline system. The most comparable piece of currently operational equipment is selected as most similar to the equipment placed on a new proposed weapon system. The failure rate for the new equipment is a decrement or an increment of the real MDC data for the comparable existing equipment. This determination is made by engineering and logistics experts at the Air Force Human Resources Laboratory. These new hardware characteristics are then fed into the LCOM model and flying the aircraft is simulated within the environment of the new maintenance characteristics.

It would be possible to use failure rates determined by specifications or demonstrated in reliability tests since improvement curves for reliability as a function of testing and correction are well established. However, it is also true that field maintenance work occurs five to ten times as frequently as the "true" failures demonstrated on carefully built prototype equipment facing ideal test conditions. Initial testing monitored through the Air Force Test and Evaluation Center (AFTEC) does not provide a large enough statistical data base, and is further limited by design changes and deficiency corrections.

To establish comparability for avionics equipment, the following characteristics are considered in selecting an existing piece of equipment that is most similar to the proposed equipment: function, parts count, operating power, complexity, interconnects and multiplexing, cooling and pressurization, vibration, number and type of rotating electro-mechnical components, solid state versus tube, number of connectors and operator controls, and the number and type of signals displayed. A sample comparability assessment is presented in Appendix C.

Although not used before DSARC II, the LCOM approach to estimating maintenance manpower could be exercised at any time during the acquisition process. A weapon system could conceptually be built on paper using the comparability analyses approach to maintenance manpower estimating.

d. MOD-METRIC Model

The MOD-METRIC spares inventory management model provides a mathematical optimization technique for determining optimal stock levels of spares. Specifically, it is designed to calculate the optimum mix of recoverable spare parts that can be purchased with a specified budget while minimizing base unfilled demands (backorders).[1]

The model identifies the logistics relationship between an assembly and its sub-assemblies. The logistics relationship is defined by average resupply time of the assembly, MTBFs for the assembly and its components, and the average resupply time for each of the components. When processed to optimize spare stock levels at the base and depots levels, the model minimizes total expected base backorders for a piece of aircraft hardware, such as a piece of avionics equipment, subject to a spares investment constraint. By solving the model for different spares investment constraints, a minimum expected base backorder curve, like the curve in Figure 7, can be generated for different quantities of dollars spent on spares. This curve can then be used to determine a level of spares investment that will be consistent with a certain spares optimization level.

Each point on a backorder-investment (BOI) curve in Figure 7 represents a minimum backorder quantity obtainable with a given amount of spares investment dollars. Thus, for quantity of spares investment I_A, the minimum backorders

[1]Recoverable items are significant in that they represent about two-thirds of the Air Force spares investment total.

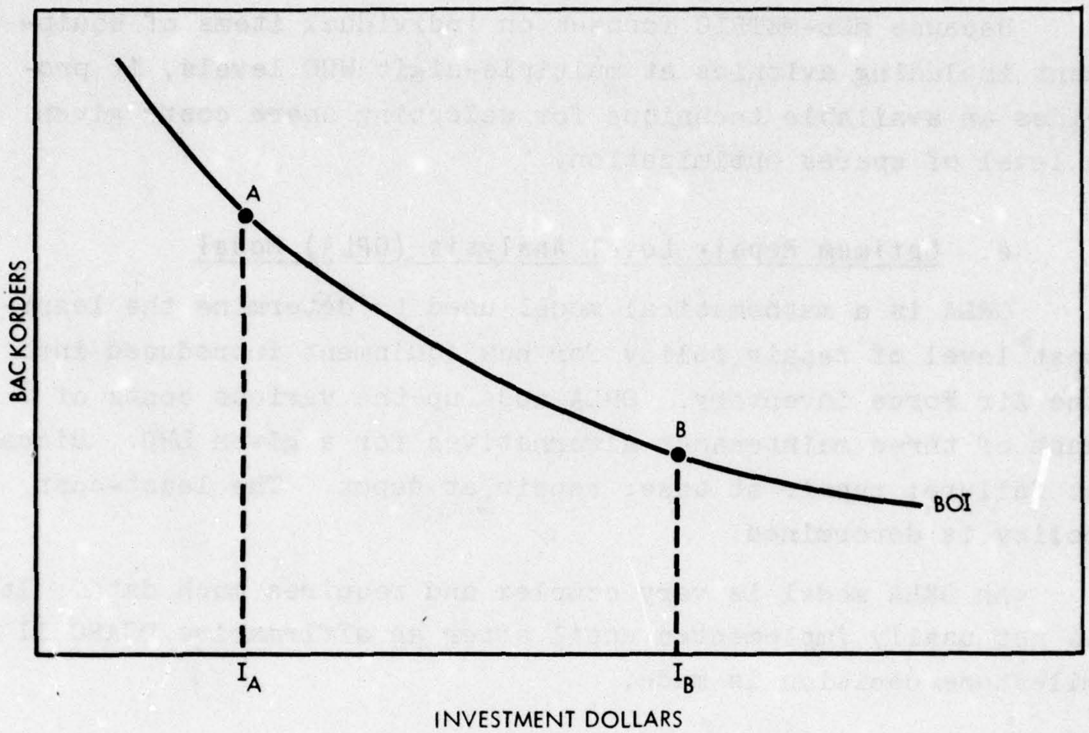

Figure 7. MOD-METRIC BACKORDERS VERSUS INVESTMENT CURVE

obtainable for a given set of LRUs and SRUs is backorder quantity A. The MOD-METRIC model uses the I_A investment amount as a constraint, and the minimum backorder quantity A is calculated. In the process of calculating minimum backorders A, the model also allocates the given dollars I_A to LRU and SRU spares, thus determining the optimum spares to buy given that dollar total.

Inputs to MOD-METRIC include specific equipment characteristics such as frequency of removals, average resupply items, NRTS rates, and average repair times at base and depot. A maintenance concept and a repair level analysis must also be specified in the model.

Because MOD-METRIC focuses on individual items of equipment including avionics at multiple-digit WUC levels, it provides an available technique for selecting spare costs given a level of spares optimization.

e. Optimum Repair Level Analysis (ORLA) Model

ORLA is a mathematical model used to determine the least-cost level of repair policy for new equipment introduced into the Air Force inventory. ORLA adds up the various costs of each of three maintenance alternatives for a given LRU: discard at failure; repair at base; repair at depot. The least-cost policy is determined.

An ORLA model is very complex and requires much data. It is not usally implemented until after an affirmative DSARC II milestone decision is made.

f. Avionics Equipment Support Cost Parametric Cost Estimating Relationships

(1) Avionics Laboratory-Sponsored Research

Two recent Air Force Avionics Laboratory (AFAL)-sponsored studies have produced avionics equipment support cost CER's. Volume 1 of the earlier study, *Cost Analysis of Avionics Equipment* (February 1974), contains parametric annual maintenance cost equations for doppler radars, computers, fire control radars, and a general avionics equipment CER. For doppler radars, general equipment, and computers, the only independent variables in the equations are procurement costs. As an example, the general equipment maintenance equation is LOG cost = $-1.62 + 0.86$ $LOGX_1$, where cost is annual maintenance cost per unit and X_1 is culmulative average cost at 1000 units of production.

The fire control radar maintenance equation uses peak power in kilowatts as its independent variable, and is of the specific form:

$$\text{LOG cost} = -2.086 + 0.611\ \text{LOG}X_1.$$

The later AFAL-sponsored study *CERs for Airborne Array Radars, FLIRs, and Avionics Logistic Support,* went a step further and included MTBF as a second independent variable along with procurement cost. As an example, the maintenance cost CER for inertial measurement units (IMUs) is

$$\text{LOG } C = 5.432 + 0.0214\ \text{LOG}X_1 - 0.577\ \text{LOG}X_2,$$

where C is annual maintenance cost, X_1 is IMU procurement cost, and X_2 is MTBF in hours. The R^2 coefficient of determination is only .348, which indicates that only a third of the changes in IMU maintenance cost are explained by the two independent variables. Higher coefficients of determination were obtained for other variables, but the wide variations in coefficients of determination raise doubts about the usefulness of these specific CER's.

The key element is, of course, the data base used to run the regressions to arrive at the coefficients of the independent variables. In the earlier AFAL study, data from six different sources were used with little assessment of data quality. In the second study, IROS data provided the dependent variable maintenance costs and AFLC-reported data provide the MTBF's for each type of equipment by AN-number. The IROS data were noted as deficient in base material and depot activity costs, so a cost factor multiplier was determined that could expand the IROS-based results to reflect total maintenance costs. The factor of 2.17 is based on a life cycle cost study of the A7D aircraft and is explicitly qualified as only uncertainly applicable to other weapon systems.

These qualifications to the latest Avionics Laboratory equipment level support cost parametric CERs highlight the major stumbling block in developing avionics equipment level CERs--reliable data. Conceptually there is no reason that logistic support CERs should be difficult to develop for existing avionics equipment. However, the data problem is not as simple as arriving at more and better data, because this problem is related to another that applies to the basic methodology used in the past to develop avionics equipment support cost CERs. Conceptually, better data not only means numbers that more truly reflect the actual field experience with avionics equipment, it also means collecting data in meaningful categories. To determine what is meaningful requires knowledge about the key independent variables that influence support costs before going out to gather the data. As the earlier AFAL study admits, regressions are frequently run to determine which are the significant variables instead of the other way around--running regressions to try to disprove the hypothesis that the selected variables are not the correct variables. Thus, it appears that because of the dictates of necessity and data, regressions are often run first to pick out key variables. But ascribing this measurement-before-theory practice to necessity does not diminish its weak conceptual basis. Existing avionics equipment support cost CERs as represented by the AFAL studies in 1974 and 1975 carry little confidence in their calculated coefficients. Until theoretical conceptualizations of avionics equipment cost drivers are offered for empirical testing, avionics support cost CERs will be suspect at any stage of the acquisition process.

(2) <u>CACE Factors Model</u>

The Air Force Cost Analysis Cost Estimating (CACE) model is a variation of the regression approach. It uses cost factors developed through regression analysis to estimate recurring investment and miscellaneous logistics costs including base

maintenance material, depot maintenance labor and material, Class IV modifications and their initial spares, and replenishment spares. These estimates are all at the weapon system level.

Key parameters of a proposed weapon system are multiplied times factors, some of which are developed by regression equations, to generate estimates for the cost elements represented by the factors. The regression-developed factors are frequently functions of the new proposed weapon system's acquisition cost and physical characteristics. As an example, replenishment spares cost per flying hour (RS$/FH) could be the dependent variable in a regression equation where the independent variables are avionics production cost, engineer production cost, airframe production cost, maximum aircraft speed, and aircraft empty weight.[1] The form of the functional relationship may vary, but the reliance on historical data regressed against aircraft cost and physical data remains.

The CACE-type model is the standard Air Force format within which operating and support costs estimates are prepared for DSARC submission, but it does not provide a component estimate capability.[2]

4. DATA AND MANAGEMENT INFORMATION SYSTEMS

a. Overview

The key Air Force data and management systems that provide support cost data to the various models and techniques described in the previous sections are discussed below. Their basic outlines are offered as indications of what is available. No

[1]This is basically the approach taken by the Navy for total aircraft support cost estimates. The equations used in the F-18 top level model discussed later in this chapter resemble the CACE factor regression equations.

[2]The Navy takes independently developed total weapons system equations similar to the CACE equations and extends them to the F-18 NAVAIR subsystem tacking model discussed later in part C.

attempt to provide detailed expositions of the data systems is intended.

b. Operating and Support Cost Estimating Reference (OSCER)

OSCER is a management information system that responds to part of the SECDEF requirements for a Visibility and Management of Support Costs (VAMOSC) system. Specifically, OSCER organizes data inputs form fourteen existing data systems into the operating and support cost elements and sub-elements shown in Table 3 for MDS aircrat. It does not report support costs at the individual component level. The cost accounts into which data are reported and subsequently organized into the cost elements in Table 3 are displayed in Appendix D.

The reported costs are distributed to weapon system MDS either by allocation or estimation. Some of the cost element data are based on direct input accounting systems, including the data for unit operations, below depot maintenance, base installation support, second destination transportation, and depot installation support. These data are then allocated to MDS. Depot maintenance data are input through the depot maintenance industrial fund accounting and production reporting system (HO 36), but this accounting system utilizes standard rather than actual costs and common item maintenance costs are allocated to weapon systems. As a result, depot maintenance data are more accurately identified as "factors" than as direct accounting inputs. Other cost elements and sub-elements that are factored include POL, replenishment spares, training munitions, personnel training, PCS, and medical. Thus, for the O&S costs (for FY 76) reported in OSCER for a modern fighter aircraft like the F-15A, the direct accounting data cost elements accounted for 59% of the total reported costs, and the factored data cost elements, including depot maintenance, accounted for 41% of the total reported costs. Similar proportions for other

Table 3. OSCER COST ELEMENTS AND SUB-ELEMENTS

Cost Element	Sub-Elements
UNIT OPERATIONS (Identified under the mission program element in the major force program structure)	Aircrew Command Security POL
BELOW DEPOT MAINTENANCE (Identified under the mission program element in the major force program structure)	Chief of Maintenance Avionics Consolidated Field Munitions Airborne Missile Organizational
SUSTAINING INVESTMENT (Identified under the mission program element in the major force program structure)	Replenishment Spares Replacement MOD Kits/Material Ground Support Equipment Training Airborne Missile Training Munitions
INSTALLATION SUPPORT (BASE) (Identified under the support program element in the major force program structure)	Real Property Maintenance Communications Base Operations
ADVANCED TRAINING (Flying Status) (Identified under the support program element in the major force program structure)	Officer Enlisted
DEPOT MAINTENANCE (Major force program 7)	PDM/MOD Engines Avioncs Other
DEPOT SUPPLY ACTIVITIES (Major force program 7)	Distribution Materiel Management Procurement Technical Support
SECOND DESTINATION TRANSPORTATION (Major force program 7)	
INSTALLATION SUPPORT (DEPOT) (Major force program 7)	Real Property Maintenance Communications Base Operations
ADVANCED TRAINING (Major force program 8)	Officer Enlisted
HEALTH CARE (Major force program 8)	
PERMANENT CHANGE OF STATION (Major force program 8)	
INSTALLATION SUPPORT (Major force program 8)	Real Property Management Communications Base Operations

MDS aircraft O&S costs in the FY 76 OSCER report support the conclusion that more than half of the O&S costs in OSCER are based on accounting data allocated to MDS (not directly reported to MDS), and the remaining O&S costs are factored.

The allocation methodologies for depot and base maintenance are too complex to pursue here, but the replenishment spares methodology is relatively straight-forward and permits us to examine a detailed OSCER factoring approach. For a given MDS, the cost of replenishment spares (R_i) is given by the equation

$$R_i = (C)\ \frac{\text{Depot Maintenance Repair Cost}}{(.97)(.145)}\ .$$

The numerical constants in the equation are derived as follows. For a given fiscal year, the depot maintenance costs associated with all work breakdown structure groups (excluding programmed depot maintenance and engine repairs) averaged 14.5% of the inventory value of NRTS items. Also for a given fiscal year, 3% of NRTS items (C) resulted in depot condemnations (and 97% were repaired). If X is the value of the NRTS inventory, then depot maintenance repair cost (D) is given by

$$(.97)(.145)X = D.$$

Rearranging the equation, X, the value of the NRTS inventory is

$$X = \frac{D}{(.97)(.145)}\ .$$

Since 3% of the items are condemnations and are to be replaced with replenishment spares funds, the OSCER approach is to multiply the condemenation percentage times the value of the total NRTS inventory, as shown in the equation below:

$$R = CX$$

$$R = .03X\ .$$

This provides an aggregate estimate of replenishment spares costs for the entire Air Force. But to use the equation at the MDS level, it would be necessary to know the NRTS inventory

value by MDS, and these data are not available in any existing reporting system. However, because the inventory value of NRTS items is equal to depot maintenance repair cost (D) divided by the two numerical constants (.97 and .145), and because depot maintenance repair cost data are available by MDS in the Depot Maintenance Industrial Fund Accounting and Production Reporting System (HO 36),[1] replenishment spares costs by MDS can be calculated by transforming the simple equation from condemnation rate times inventory value to condemnation rate times what inventory value by MDS is equal to. Thus,

$$R_i = .03X_i ,$$

then if $$X_i = \frac{Di}{(.97)(.145)} ,$$

$$R_i = .03 \frac{Di}{(.97)(.145)} ,$$

and $$R_i = .2133\ D_i ,$$

where R_i = replenishment spares by MDS,

X_i = NRTS inventory value by MDS,

.03 = condemnation rate percentage of NRTS items,

.97 = NRTS items repaired at depot,

.145 = total depot maintenance cost as percentage of total NRTS inventory value,

.2133 = numerical factors combined and simplified,

d_i = depot maintenance repair cost by MDS.

Thus, the OSCER equation allocates replenishment spares to MDS on the basis of depot maintenance repair costs by MDS as the weighting factor (and combined with the numerical values identified above).

[1]Common items are prorated to weapon systems in the data system.

The OSCER cost equations are characterized by factors and allocations like those in the replenishment spares equation. Even if OSCER were designed to provide costs by equipment levels such as two- or five-digit WUCs, which it is not, it is doubted that the equations would provide useful results. Similar criticisms apply to the Navy's weapon system level VAMOSC report, but not to its maintenance subsystem report which uses direct data inputs by seven digit WUC to build its maintenance and replenishment spares cost reports.

The Air Force is currently constructing an equipment level LRU and SRU maintenance data VAMOSC reporting system separate from the OSCER effort. This equipment level system has not yet produced a published report.

c. Increase Reliability of Operational Systems (IROS)

The IROS program identifies equipments that are high consumers of logistic support cost. As of March 1, 1977, this is being done for thirty-seven aircraft, ten aircraft engines, two missiles, ninety-one communications-electronics-metrological equipments, and sixteen munitions handling equipments.[1] The identification and ranking of equipment high cost consumers is at the five-digit WUC level of detail. The data are accumulated quarterly in the KO 51 data system, with substantial data collected on a daily basis in the AFM 66-1 equipment status reporting system, and several Depot Level Repair Management Systems. The costs reported into IROS include base labor, depot labor, depot materials, cost of condemnations, transportation, and packaging-shipping costs. IROS data exclusions

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[1]A 1975 RAND Report, R-1569-PR, *An Appraisal of Logistics Support Costs Used in the Air Force IROS Program,* by M. Fiorello and P.K. Day suggests that the IROS reports could be made more useful by capturing the costs for which they are designed, including base material, planned depot maintenance, and engine repair, and by extending coverage to include base and depot AGE maintenance, pipeline spares, modification hardware, and others.

include some elements of base material, planned depot maintenance, and engine repair. A January 1974 IROS briefing package suggests that "...extreme difficulty is being experienced in accumulating parts costs at base and intermediate levels," and advises that IROS costs do not include the cost of field level parts replaced.[1] In addition, the IROS briefing warns that there are many depot level activities not related to a WUC so the costs shown in IROS are lower than actual costs experienced during programmed depot maintenance.[2] Thus, IROS accumulates only some of the data elements relevant to the support costs of maintenance at all levels and spares and repair parts support.

The AFLC data systems that provide inputs to IROS include:

DO 43	Cataloging Data
DO 33	Aerospace Vehicle Inventory and Equipment Status Report
DO 56	Product Performance System
DO 24I	Engine Configuration System
DI 43	Management Division and Technical Identification
GO 11	TIRES
GO 81	Lockheed C-5A MADARS/Ground Processing System
GO 26	Material Improvement Program.

Given the coverage and exclusions of IROS data, it is possible to extract some logistic support costs from IROS for the five-digit WUCs on a given aircraft. A sample summary IROS support cost ranking of five-digit WUCs on a given MDS is displayed in Table 4. These and similar rankings of relatively high support cost equipments are the intended outputs of IROS. As an example, WUC 23BAE in Table 4 is the twenty-sixth highest ranking support cost consumer among the equipments on a given

[1]*IROS,* Air Force Logistics Command, January 1974.

[2]IROS weapon system and equipment coverage is given in Appendix F.

Table 4. SAMPLE IROS SUPPORT COST RANKING OF FIVE-DIGIT WUC'S ON AN MDS AIRCRAFT

			AVERAGE MONTHLY VALUES							
		PROP	CURRENT QTR		1ST PREV QTR		2ND PREV QTR		3RD PREV QTR	
WUC	NOUN	SHARE	RANK	LSC	RANK	LSC	RANK	LSC	RANK	LSC
23AU0	HT INST ENG TH	0.021	521	$124		$737		$1206		$170
23AXX				$10457		$11478		$12881		$3812
23BAB	LINK EXT GR BOX					$1		$1		$1
23BAC	PIPE ASSY AIR 7	0.001	1789	$4		$1		$9		$8
23BAD	DUCT ASY FWD BY					$54		$1		$1
23BAE	DUCT ASY RER BY	0.752	26	$4459		$26		$516		$25
23BA0	BASIC ENG ASSY					$152		$87		
23BBA	GR BOX ASSY HI	0.016	638	$92		$32		$10		$98
23BBB	GR BOX ASSY LOW	0.004	1237	$21		$73		$3		$1
23BB0	ACC DRIVE ASSY					$1		$1		$7
23BB9	NOC	0.001	1801	$4						
23BCA	CAP SPINNER NOS					$1		$1		$1
23BCD	WHEEL LP COMP S	0.006	982	$38		$37		$370		$139
23BCE	BLADE LP COMP S	0.002	1525	$10		$80		$137		$25
23BCF	CASE ASSY FWD L	0.003	1262	$20		$5		$17		$11
23BCH	MEMBER FR STK S					$1		$1		$1
23BCJ	HOUSING FR RING					$1		$1		$1
23BCL	PLATE RET FRNT	0.001	1876	$3						
23BCP	BRNG FRNT LP CO	0.001	1654	$6		$12		$27		$1
23BCS	PLATE RET RR RN					$1		$3		
23BCX	TUBE OIL TRANSF					$1		$1		$1
23BCY	RING REAR OUTER					$11				
23BCZ	TUBE OIL FEED					$1		$95		$1
23BC0	LOW AND INTRM C	0.029	415	$171		$181		$360		$23
23BC4	ROTOR-VANE LP 1	0.001	1815	$3		$1		$12		$1
23BC6	SEAL ROTAT LABY	0.002	1471	$12						
23BC7	BRNG LP COMP RR					$1		$1		$1
23BDA	CPLG HP COM 1P					$1		$1		$1
23BDB	VANE ASY IP OL					$1				
23BD9	NOC					$17		$1		$6
23BEA	SPT INTERMED CO	0.001	1661	$6		$3		$1		$1
23BEB	GR BOX ASSY INT					$5				
23BED	HSNG SL HP COMP					$36		$5		
23BEE	VANE INLET GUID	0.000	1951	$1		$1		$1		$1
23BEF	ROTOR ASY HP CO	0.002	1485	$11		$264		$1132		$28
23BEG	BRNG TH LP DR N	0.003	1276	$19		$2				
23BEH	BRNG TH HP COMP					$1		$1		$1
23BEJ	TUBE-FILTR OIL	0.005	1125	$28						
23BEK	COMP CASE-VNE H	0.001	1854	$3		$3				
23BEL	DIFF-BRG HSG HP					$24				
23BEP	TUBE TRNS OIL F	0.018	590	$104		$1		$1		$1
23BE0	HP COMP SECTION					$678		$792		$373
23BE9	NOC	0.001	1864	$3						

MDS in the current quarter reported. Logistic support costs by IROS categories are also available as IROS outputs as shown in Table 5.

d. DO 56B - Maintenance Actions, Manhours, and Aborts by WUC

This report provides on- and off-equipment historical information on maintenance actions, manhours, and aborts for the past six months on every WUC included in a master record. DO 56B also serves as an historical record for each WUC, and as such provides the tracking capability for plotting trends in failures, maintenance actions, manpower resource expenditures, and aborts. The primary use of the system is for reliability and maintainability studies and for verification of modification effectiveness.

The MTBF is computed each month on all WUCs unless there are no reprorted failures for any three consecutive months within the time span covered by the report. For each monthly MTBF computation, a three-month accumulation of failures and operating time (flying hours or days) is used. The MTBF formula is as follows:

$$MTBF = \frac{(OPT)(UF)(QPA)}{FO} \left(\frac{SI}{AFM\text{-}1} \right),$$

where:

- OPT = operating time, a three-month accumulation of flying hours or days
- UF = use factor, a ratio of item operating time to flying hours, usually = 1
- QPA = number of identical items reported under one WUC
- FO = three month accumulated failure occurrences
- SI = special inventory, applies when the inventory of a WUC applies to only a part of the fleet
- AFM-1 = computed inventory; the data in Standard Aerospace Vehicle and Equipment Status Reports are used to compute inventory for aircraft and other weapons.

Table 5. SAMPLE LOGISTIC SUPPORT COST BREAKDOWN FOR MDS A007D CURRENT QUARTER COMPUTATION DATA AS OF AUGUST 1973

		QUARTERLY VALUES					
WUC	NOUN	FIELD MAINT	SPEC REPAIR COST	PACK/SHIP COST	CONDEMNATION COST	BASE MATERIAL COST	TOTAL QTR LSC
73ECA	ASSY FAN	$71	$0	$0	$0	$0	$71
73EC0	MT ELECT EQUIPM	$345	$0	$0	$0	$0	$345
73E00	DIS SYS HEADSUP	$16,501	$0	$0	$0	$0	$16,501
73Exx		$126,383	$19	$2,261	$0	$0	$128,663
73FA0	BOARD CAPRI	$143	$71	$1	$0	$0	$215
73FAE	MODULE GIMBAL L	$307	$57	P $0	$0	$0	P $364
73FAF	MODULE PWR SUP	$269	P $424	P $9	$0	$0	P $702
73FAG	MODULE MODE SWI	$136	$342	$3	$0	$0	$481
73FAS	GYROSCPE ELECTR	$26	$0	$0	$0	$0	$26
73FA0	UNIT INERTIAL M	$51,740	P $321,868	$3,424	$0	$0	P $377,032
73FA9	NOC	$5	$0	$0	$0	$0	$5
73FB0	RACK ELEC EQUIP	$140	$0	$0	$0	$0	$140
73FCB	FRONT PANEL	$2	$0	$0	$0	$0	$2
73FC0	CONTROLLER IMS	$1,362	$196	$3	$0	$0	$1,561
73FC9	NOC	$21	$0	$0	$0	$0	$21
73FDB	CARD SEQUENCER	$121	$300	$2	$0	$0	$423
73FDC	CARD SEQUENCER	$106	$98	$1	$0	$0	$205
73FDD	MODULE 800 HZ	$158	P $0	$1	$0	$0	P $159
73FDE	MODULE HEAD REP	$849	P $1,011	$22	P $0	$0	P $1,882
73FDG	CARD RELAY DRIV	$197	P $196	$3	$0	$0	P $396
73FDH	CARD RELAY DRIV	$111	$228	$2	$0	$0	$341
73FDK	DRIVER AMPLIFIE	$15	$0	$0	$0	$0	$15
73FDL	POWER SUPPLY	$74	$0	$0	$0	$0	$74
73FDM	CARD PWR SUPPLY	$143	$588	$8	$0	$0	$739
73FDN	CARD PWR SUPPLY	$32	$0	$0	$0	$0	$32
73FDP	CARD PWR SUPPLY	$150	$192	$7	$0	$0	$349
73FDQ	CARD PWR SUPPLY	$165	$504	$12	$0	$0	$681
73FDR	CARD PWR SUPPLY	$45	$100	$1	$0	$0	$146
73FDS	MODULE BITE	$28	$144	$1	$0	$0	$173
73FDU	MOTHER BOARD MO	$28	$0	$0	$0	$0	$28
73FD0	ADPTR PWR SP LS	$36,970	P $0	$28	$0	$0	P $36,998
73FD9	NOC	$10	$0	$0	$0	$0	$10
73FE0	MOUNT ADPT/PS	$78	$0	$0	$0	$0	$78

Mean time between maintenance actions (MTBMA) is computed for each month for each WUC using the same formula as for MTBF above, except that the FO (failure occurrences) term is replaced by TO, total maintenance action occurrences.

The DO 56 system permits a six-month total for each WUC to be the output for:

(1) operating time
(2) aborts or mission failures
(3) failure, other malfunctions, and total occurrences
(4) six months MTBF
(5) six months MTBMA
(6) scheduled, unscheduled, and shop manhours
(7) repaired, condemned, and NRTS items listed.

e. GO 33 - Aerospace Vehicle Inventory, Status and Utilization Reporting System (AVISURS)

Statistics relative to flying hours, landings, and sorties accomplished by an aerospace vehicle during the report month are reported in this data system. The system applies to aircraft, selected missiles, communications-electronics-meterological equipment, and trainers.

The data are used in conjunction with the DO 56 data to compute MTBFs and to provide NORS data for evaluating maintenance and supply effectiveness.

The data flow is from the GO 33A system at the base to the GO 33C system at major command to the the GO 33B system at AFLC headquarters. The systems are managed in accordance with AFR-65-110. Information derived from GO 33 statistics is used by logistics management to establish requirements pertaining to the general support of aerospace vehicles. In addition, the flying hours reported are used to update the Accumulated Life Cycle Airframe Hours for each aerospace vehicle, identified by serial number, in the Aerospace Vehicle Master Inventory. Each

Air Force Activity possessing Aerospace Vehicles is required to report flying hours, landings and sorties by mission symbol on an as-occurs basis.

The Utilization Subsystem supports the monthly and quarterly data. This subsystem is processed monthly, with additional outputs on a quarterly basis. Data are received from each major command and each base possessing aerospace vehicles. All major commands possessing aerospace vehicles submit a monthly summary of flying hours, landings and sorties for each mission accomplished, denoted by mission symbols.

f. GO 78C - Inertial Navigation Systems (INS) Data System

The GO 78C Data System provides a complete record of test, removal, and repair data for each identified Inertial Measurement Unit/Inertial Reference Unit (IMU/IRU) and its components. The data that are recorded for GO 78C contain information concerning failures identified during test and repair actions.

When an IMU/IRU or Not Repairable This Station (NRTS) component is sent to a depot, identification, failure, repair data and elapsed time readings are recorded. This becomes the primary source of data for the GO 78C system and all data are retained in the main data bank for 25 months. In order to retrieve data for a longer period of time, special programming efforts are necessary. Such data permit a comprehensive data base for engineering analysis of inertial navigation systems.

The GO 78C products are divided into three basic groups. The first group of products contains test, failures and repair histories applicable to serialized assemblies and components. The second group of products contains population data which depict summary information applicable to an IMU/IRU, a component, or parts removed from a component. Third, a management report contains 12 months of data recorded for a particular part numbered IMU/IRU.

g. DO 57F - Failure Program

The Actuarial Analysis Program is a unique system correlating usage and failure data for analyzing equipment reliability, developing actuarial life expectancy factors, and forecasting failures. It has been successfully applied to propulsion systems, aircraft propellors, certain helicopter components, and is now being applied to other selected air vehicle components. The method or technique is applicable to any item that shows a relationship between usage and aging of the item, regardless of the type of time in which that usage is measured.

The Air Force actuarial method consists of the development and use of actuarial mathematics, studies in life contingencies, and the theory of probability, primarily for accomplishing forecasts of materiel failures and for the analysis of problems related to materiel failures.

The Air Force requires dependable forecasts of material failures to support planning for

(1) repair facilities
(2) spares procurement
(3) overhaul schedules
(4) budget requests
(5) manpower and skills.

The Air Force Actuarial Program is based on the theory that items fail at various rates at successive ages. Age can refer to a variety of time measures, including starts, stops, landings, cycles, rounds, operating time, and cumulative calendar or clock time. The identification of failure patterns is a crucial step in problem solution, and continuous tracking of the failure pattern and rate is necessary to identify changes in item performance resulting from aging or the quality of overhauls.

A failure is defined as a condition requiring item removal either because of inadequate performance requiring field maintenance repair or inadequate performance requiring depot maintenance action. Failures are the basis for mean time between failure (MTBF) measures, which amount to the total flying (operating) hours for a time period divided by the failures for the period.

The DO 57F system increases visibility of time and failure information for the development of actuarial reports and factors. The system can produce actuarial reports on any item selected by identifying the individual National Item Identification Number. Within a weapon system, the decision must be made as to which equipments will benefit from actuarial tracking. Those items that are expected to fail as a function of age, move as a unit through the repair cycle, or are items that require precise forecasts for spare buying or overhaul planning are all prime candidates. High cost nonrecoverable items are also included in DO 57F coverage.

h. HO 36 - Depot Maintenance Cost Accounting Production Report

The HO 36 depot maintenance industrial fund (DMIF) cost accounting production report provides for the accumulation, recording, and reporting of all cost and production data related to depot maintenance. These data include civilian and military labor, direct materials cost, and contractor maintenance services.

The data are accumulated from two major depot maintenance data systems: (1) the GO 72A depot maintenance production cost system, and (2) the GO 72B depot maintenance production cost system for inertial guidance systems. These two data systems are summary systems that receive input data from more than twenty other systems, including:

(1) Maintenance End Item Reporting GO 04L

(2) Maintenance Labor Distribution System, GO 37C
(3) Maintenance Actual Material Cost, GO 04H
(4) Contract Depot Maintenance Production and Cost System, GO 72D
(5) AFLC Retail Stock Control and Distribution and Central Material Locator System, DO 33
(6) Work Measurement and Labor Control System, CO 04B
(7) Maintenance Management Data System, GO 35A.

These seven systems are themselves quite complex, and a complete detailed examination of their contents, as well as the other input systems to HO 36, is beyond the scope of this paper.

5. Summary

This section examined the Air Force methodological approaches to estimating avionics support costs for fighter aircraft. The most frequently used component level model is the AFLC LSC model, usually for source selection and DSARC II. Its level of detail is substantial in that it goes to the FLU level of equipment and provides support cost estimates in several categories including field and depot maintenance and initial and replenishment spares.

Regression models developed by the Air Force are either not based on broad enough support cost data bases (the Avionics Laboratory funded studies to date) or are not used for component level cost estimates (CACE).

Models like the LCOM, MOD-METRIC, and ORLA could be utilized early into the estimating sequence of the acquisition cycle at DSARC 0 or I, but require substantial analogy detail and engineering judgments to be applied in these early acquisition cycle phases. The LSC model could also be utilized early in the acquisition cycle through the use of analogy data inputs.

Air Force data systems provide considerable component support cost detail, but not in a single integrated data management

reporting system. The OSCER VAMOSC system could potentially provide this service, but currently does not extend to the component level.

C. NAVY METHODOLOGIES, POLICIES, AND DATA SYSTEMS

1. Introduction

Support costs[1] for avionics equipment on fighter aircraft are not routinely estimated by the Navy until after the full-scale engineering development decision milestone (DSARC II) in the major weapon system acquisition process. We believe that although avionics equipment-level support cost estimates are first produced relatively late in the acquisition process, the capability to produce them earlier does exist in the form of appropriate Navy methodologies and specific cost estimating models discussed in this paper.

The earlier discussion of Air Force support cost estimating methodology stressed the temporal flexibility of Air Force cost estimating techniques. The same stress is placed here on the flexible applicability of Navy techniques with regard to when they are applied in the major weapon system acquisition process. Critical assumptions about the data used in these specific cost estimating methodologies are discussed later. The argument is that most of the necessary data inputs exist before, during, and after any given milestone in the acquisition cycle, so that the application of a specific cost estimating technique is largely a matter of policy, not a matter of data or estimating technique availability.

The current Navy fighter aircraft development project is the F-18. This specific case offers a current example of

[1]Support costs refer to maintenance at all levels, spares, and repair parts support. This is a narrower definition than "operating and support" costs, such as that offered in Norman E. Betague, Jr. and Marco R. Fiorello, *Aircraft System Operating and Support Cost: Guidelines for Analysis*, Logistics Management Institute, Washington, D.C., March 1977.

avionics equipment support cost estimating. Prior to DSARC II, avionics is treated at a highly aggregated level in total weapon system operating and support (O&S) cost equations that contain avionics acquisition cost estimates as independent variables. Once DSARC II is completed, NAVAIR implements an O&S baseline tracking model. This baseline O&S model permits the Project Manager, Air (PMA) to track support cost trends at the two-digit work unit code level. This internal NAVAIR O&S model is separate from the O&S subsystem model operated by the prime contractor following DSARC II, which is a level of repair (LOR) analysis-based model. In addition to these models used for the F-18 program, the Navy has a Life Cycle Cost model similar in structure to the Air Force LSC model, the CASEE aircraft maintenance simulation model,[1] and spares optimization models.

2. Policies and Procedures

Navy policies and procedures for estimating avionics support costs on fighter aircraft are included under the umbrella of the general cost estimating policies and procedures that the Navy has established to comply with DoD regulations.[2]

As discussed in the Air Force section of this chapter, if the mission need for a new Service system acquisition is identified as a major cost saving advantage over an existing system at DSARC 0, it is possible that cost estimates even at DSARC 0 milestone could be required. Whether cost estimates would be at the two-digit WUC level or lower would depend on the specific mission need and upon the source of the cost-saving opportunity.

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[1]CASEE is the Carrier Aircraft Support Effectiveness Model, discussed in greater detail later.

[2]The key Navy policies are contained in SECNAVINST 5000.1, *System Acquisition in the Department of the Navy,* OPNAVINST 5000.42A, *Weapon Systems Selection and Planning,* and OPNAVINST 5000.46, *Decision Coordinating Papers (DCPs), Program Memoranda (PMs), and Navy Decision Coordinating Papers (NDCPs).*

Barring such a situation, Navy policy is to first estimate support costs at a highly aggregated level for DSARC I, perhaps showing separately for the aircraft, estimates for airframe, propulsion, and avionics and providing lump-sum support cost estimates for each of these systems.

For the validation phase (DSARC I) the system-level cost estimates are developed through parametric regression equations derived from Naval Air Development Center (NADC) research in the late 1960s.[1] If alternatives are provided at DSARC I, costs are estimated for all alternatives using the same model. A preliminary Weapon System Planning Document (WSPD) identifies procurement size, potential base loading, carrier outfittings, trainer requirements and depot capabilities. A comparison system from the current active inventory of fighter aircraft is selected as the best analogy to the proposed aircraft, and judgments are made about anticipated differences in size, complexity, and operational environment between this analogy comparison system and the proposed systems.

During the period of time leading to the full-scale development milestone decision (DSARC II), the potential systems are well-defined, although not necessarily designed. The WSPD has been developed and promulgated to interested contractors, and the source selection is made. The source selection is not made based on avionics equipment-level support cost estimates. These estimates are only at the total weapon system-level of the aircraft.

Interim support spares and repair parts cost estimates are made based on flying hour cost. The cost per hour is estimated considering the costs of past systems and contractor proposals.

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[1]S. Getz, *Techniques for Estimating Logistics Support and Operations Cost of Naval Airborne Weapon Systems (U)*, Report No. NADC-SD-1925, Naval Air Development Center, Warminster, PA, April 30, 1969.

These basic policies and procedures are implemented through specific models and methodologies for cost estimating, which we examine in the next section.

3. Cost Estimating Methods

a. The F-18 Total System Model

(1) Basic Form and Uses

The Navy's DSARC II F-18 cost presentation was based on the outputs from an eight equation cost model that generated O&S costs for the entire aircraft, but not for specific pieces of equipment, including avionics. The eight dependent variables estimated by the equations are:

(1) Enlisted maintenance and operating personnel per squadron,
(2) Enlisted administrative support personnel per squadron,
(3) Airframe rework cost,
(4) Engine rework cost,
(5) Component rework cost,
(6) Replenishment spares costs,
(7) POL cost,
(8) Other consumables cost.

The equations for airframe rework, component rework, replenishment spares and other consumables are regression equations. The other costs are estimated by simple algebraic relationships.

Besides proving the absolute dollar values for O&S costs submitted at the DSARC II milestone, this total system model is used to track these costs throughout the full scale development program and well into the production program. It was disaggregated following DSARC II into a baseline subsystem cost tracking model operated by NAVAIR and discussed later in this paper. Because these costs are disaggregated to the two-digit WUC level in the baseline tracking model, it is appropriate to

carefully examine the total system model equations in the next section.

The eight cost variables listed above are described by NAVAIR and McDonnell Douglas Aircraft Corporation (MCAIR, the F-18 prime contractor) as representing the direct O&S costs for the F-18 as they will accumulate over time, per the Weapon System Planning Document (WSPD). The total system cost model equations are designed to reflect the influence of F-18 design parameters on total O&S costs. The costs (dependent variables) were selected from the direct costs listed in the Navy Resources Model (NARM),[1] except for the personnel costs which include direct and indirect costs.

The NARM costs are the values for categories such as component rework, engine rework, and airframe rework, for several aircraft. These values are inputs to the regression model and are used as the dependent variables to be regressed against aircraft characteristics in the regression model. Because these NARM values are budget-constrained numbers, it is uncertain that they represent the true physical relationships between aircraft characteristics and support costs. In the technical language of regression analysis, the equations are misspecified because the NARM-derived dependent variables may be the result of budgeting

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[1]The NARM (Navy Resources Model) is a computerized data management system, operated by OP-901 and used by the Navy to illustrate the distribution of total Navy resources. Originally conceived as a modeling device to provide a rapid response capability to assess the impact of changes in force levels on Navy resource requirements, its role within the Navy PPBS process is now considerably expanded. It is also used to prepare the Department of Navy Five Year Procurement Annex, the Navy Program Factors Manual, and the program years' data for the annual Navy Program Objectives Memorandum (POM) submission. All data input to the NARM may be classified either as factors or throughput. During the POM process these data are either furnished directly by the CNO-designated appropriation sponsors working closely with the Navy Systems Commands, or are derived from the data supporting the January FYDP. These data are used to determine initial allocations of funds based on the approved program.

process management decisions and not the result of true physical cost-aircraft characteristics relationships.

The F-18 DSARC II costs are derived from the 8-variable model and presented in Table 6. There are two versions of the F-18, fighter (VF) and attack (VA), and the O&S costs are presented for both versions.

Table 6. DSARC II F-18 O&S COSTS

Cost Categories	Cost per Flying Hour in FY 75 Dollars[1]		Cost per Aircraft per Year in Thousands of FY 75 Dollars[2]	
	VF	VA	VF	VA
Officers[3]	$ 258	$ 271	$108,453	$113,617
Enlisted[3]	585	585	245,797	245,797
Airframe Rework	88	88	37,136	37,136
Engine Rework	94	94	39,606	39,606
Component Rework	294	304	123,551	127,592
Rep Spares	212	219	89,242	92,592
POL	267	283	112,195	118,952
Other Consumables	205	212	86,230	89,103
Total	$2,003	$2,056	$842,210	$864,395

[1]Costs rounded to the nearest dollar.

[2]Based on utilization of 35 flying hours per month per aircraft.

[3]Includes direct and indirect personnel costs.

Source: NAVAIR, *F-18 O&S Cost*, 2 December 1975.

Based on the WSPD which provides the latest Navy policy projections of F-18 deployment and utilization plans, five and ten year O&S costs are calculated from the cost data in Table 6. At DSARC II the 5 year F-18 VF O&S costs were $2.55 billion and the F-18 VA costs were $1.78 billion; the 10 year costs were F-18 VF - $3.57 billion and F-18 VA - $2.56 billion. However,

the costs are not shown at the specific equipment level, so avionics visibility is not present in this cost estimating exercise.

(2) <u>The Regression Analysis Development</u>

The regression equations were developed by NAVAIR, MCAIR, and Information Spectrum Incorporated, a NAVAIR consultant firm.[1] The equations were then provided to MCAIR and the O&S estimates for airframe rework, component rework, replenishment spares, and other consumables in Table 6 were produced. According to NAVAIR and MCAIR, the equations were tested for significance and found to be acceptable.

The coefficients of the equations are the results of regressing data for nine Navy aircraft: A-4F, A-6E, A-7E, F-4J, F-14A, F-8J, A-6A, A-7A, and F-4B. Basic aircraft characteristic data were provided MCAIR by NAVAIR for the following categories: maximum velocity, empty weight, flyaway costs, airframe costs, avionics costs, propulsion costs, number of engines, and thrust per engine. Flyaway costs (unit production cost) estimates were derived from past and current procurements and adjusted to a 1975 base year price index. These flyaway costs on the nine aircraft were then sub-divided into airframe, avionics, and propulsion based on the experience with recent aircraft.

O&S data provided from the NARM for each of the nine aircraft include progressive air rework (PAR) cost,[2] PAR cost per flying hour, component rework cost per flying hour, replenishment spares cost per flying hour, other consumables cost per flying hour, and engine overhaul costs per flying hour. These

[1] Based on work done at the Naval Air Development Center during the late 1960s. These equations are parametric regressions.

[2] Progressive air rework (PAR) is programmed depot level maintenance performed upon accumulation of a predetermined number of calendar months or flying hours.

data provided the values of the dependent variables for the regressions which developed the coefficients in the final F-18 equations. Other O&S data provided by the Navy for the nine aircraft came from the fleet reliability and maintainability statistical summary,[1] and included mean flying hours between failure (MFHBF), mean flying hours between maintenance action (MFHBMA), and maintenance manhours per flying hour (MMHFH). Each of these reliability and maintainability measures is for the total aircraft system.

The judgment decision of which characteristics to use as independent variables is not explained by the NAVAIR or MCAIR documentation of the cost equations. They do identify the key design parameters which they believe relate best to the dependent variables, and these are summarized in Table 7. Some of these design variables are clearly proxies for other variables that are the real drivers of the O&S costs listed, but the proxies are used because the real drivers cannot be obtained. As an example, airframe and avionics costs are used as proxies for complexity in the other consumables regression equation. A detailed discussion of independent variables used as proxies in the equations is provided in the next sections which discuss each equation.

(3) Personnel Equations

The basic total system personnel equation is for enlisted maintenance personnel per squadron. Its components are: the expected direct maintenance manhours per flying hour (DMMH/FH), which is 18.04 for the F-18; the aircraft utilization rate (ACUTR); and a peacetime productivity rate of 120 manhours per month per person. K is the number of aircraft per squadron (12), and 1.82 is an expansion factor to make contractor-developed MMH

[1]Fleet Material Support Office Report 4790.A2142-01.

Table 7. KEY DESIGN PARAMETERS RELATED TO O&S COSTS AS IDENTIFIED BY NAVAIR

Costs	Related F-18 Design Variables
Direct Maintenance Personnel	Maintenance manhours per flying hour scheduled, unscheduled maintenance general support
Other Personnel Support	Function of Navy manning policy and not subject to design sensitivity
Airframe Rework	Airframe cost Maximum velocity Empty weight
Engine Overhaul	Engine pipes Modular design
Component Rework	Flyaway cost Empty weight Reliability Maximum velocity
Replenishment Spares	Flyaway cost Empty weight Reliability Maximum velocity
POL	Weight Drag Standard Fuel Consumption
Other Consumables	Airframe costs Avionics costs Reliability Maximum velocity

Source: McDonnell Aircraft Company, *Life Cycle Cost, Report No. MDC A4041*, 6 February 1976.

consistent with operational Navy experience.[1] Although the dependent variable in the equation is termed "maintenance and operating" personnel per squadron, there are no operational personnel included. The equation is

$$MO = \frac{DMMH/FH(1.82)(ACUTR)K}{120},$$

[1]The 1.82 factor was developed by the Naval Air Development Center to account for the manhours spent in activities other than direct wrench turning such as: tool and material checkout, breaks, portage time, and time utilized in reading maintenance manuals.

where:

MO = maintenance personnel per squadron

DMMH = direct maintenance manhours per flying hour

ACUTR = aircraft utilization rate

K = number of aircraft per squadron.

Maintenance management personnel are dervied by analogy with an A-7E squadron work center, totaling twenty-nine personnel: three division supervisors, nine shop supervisors, and seventeen other maintenance management and staff people.

Enlisted administrative support (EAS) is given as a function of the size of the total squadron, including officers and enlisted. The equation is

$$EAS = (-9.597 + 0.364x - 0.0009683x^2 + 0.00000113x^3)\ 1.2.$$

These numbers of maintenance, management, and administrative personnel are multipled times an enlisted billet cost of $16,478 per year, which includes direct and indirect costs based on the skill levels of a typical Navy squadron.

Flight crew officers and ground crew officers are based on standard factors and a billet cost of $61,973 per year.

(4) Airframe Rework Costs

This equation is one of the regressions discussed earlier, with scheduled depot level maintenance cost (SDLM) as the dependent variable representing airframe rework (PAR).

$$SDLM = 9.489 + 96.24(V_{max}) + 34.7(EW) + 17.910(AC)$$

where:

SDLM = scheduled depot level maintenance cost

V_{max} = maximum aircraft velocity

EW = empty aircraft weight

AC = airframe cost.

NAVAIR suggests that scheduled depot maintenance costs depend on complexity, size, material composition, operational environment, and specific design features. Empty weight (EW) is a proxy for size, maximum velocity (V_{max}) is a proxy for environment, and airframe cost (AC) is a proxy for size, complexity, and design features.

(5) Engine Rework

Because the F404 engine that is used on the F-18 is unique, NAVAIR chose not to develop a regression equation and instead performed an industrial engineering analysis to arrive at the \$94.30 cost per flying hour. The major unique feature of the F404 is that it will be overhauled and repaired in modules, not as a whole engine. The engineering base estimate is that depot overhaul and repair costs will be about 70 percent of what would be encountered with a non-modular design. Based on this estimate, an engine rework regression equation could have been prepared which incorporated a .70 degradation factor.

(6) Component Rework

The component rework (CRC) regression explains the cost of scheduled and unscheduled depot component repair. These costs are dependent on complexity, operational environment, and failure rates. The depot arrival rate is directly related to the Beyond Capability of Maintenance (BCM) categories 1 through 8 as defined by the Maintenance and Material Management (3M) system.[1] The equation is

$$CRC = 105.673 + 31.918\,[0.74(AF) + (AV+PROP)] + 8.445\left(\frac{EW}{MFHBF}\right) - 0.53916V_{max}\ ,$$

[1]BCM codes 1 through 8 define actions that require an intermediate maintenance shop to send an item on to depot for repair: repair not authorized, lack of equipment, technical skills, parts, technical data, a shop backlog, budgetary limitations, and excess of local requirements.

where:

CRC = component rework cost
AF = airframe flyaway cost
AV = avionics flyaway cost
PROP = propulsion flyaway cost
EW = empty aircraft weight
MFHBF = mean flight hours between failure
V_{max} = maximum aircraft velocity.

According to NAVAIR, empty weight (EW) is a proxy for size, maximum velocity (V_{max}) is a proxy for environment, airframe flyaway cost (AF) is a proxy for quantity of components and complexity, and mean flight hours between failure (MFHBF) is a proxy for BCM rates. The avionics and propulsion portions of flyaway costs are included as additional proxies for a quantity of components and complexity. This is the only appearance of avionics in the component rework relationship, and it is only as a lump sum of acquisition cost.

(7) Replenishment Spares

The regression equation for replenishment spares cost (RSC) takes exactly the same form as the one for component rework. It has the same independent variables and even coincidently carries the same coefficient (0.74) in the second term.

$$RSC = 76.3276 + 23.0644[0.74(AF) + (AV+PROP)] + 6.0996\left(\frac{EW}{MFHBF}\right) - 0.0389(V_{max}) ,$$

where:

RSC = replenishment spares costs
AF = airframe flyaway cost
AV = avionics flyaway cost
PROP = propulsion flyaway cost
EW = empty aircraft weight
MFHBF = mean flight hours between failure

V_{max} = maximum aircraft velocity.

Complexity, operational environment, and condemnation rates (BCM code 9) are identified as the real spares cost drivers. Again empty weight is a proxy, this time for quantity of components; flyaway costs of airframe, avionics, and engine are proxies for quantity and complexiy; and maximum velocity is a proxy for environment. Condemnation (BCM-9) rates are proxied by mean flight hours between failure (MFHBF). In the component rework equation, MFHBF was used as a proxy for all the other BCM categories except for condemnations. Although unstated, the dual use of MFHBF as the proxy for non-condemnation and condemnation depot arrivals implies an assumption about stability of the relative proportions of condemnations to the BCM depot returns.

(8) POL Cost

POL cost is estimated from the latest information on F404 engine performance characteristics.

(9) Other Consumables Costs

Other consumables (OC) consist of non-repairable material used in organizational and intermediate maintenance, repair of repairables and items related to health, safety, and welfare of the aircraft crew. The equation is

$$OC = 291 - \frac{545.7}{(AV+AF)} + \frac{18.43}{MFHBF} + 0.025V_{max}$$

where:

OC = other consumables cost

AV = avionics flyaway cost

AF = airframe flyaway cost

MFHBF = mean flight hours between failure

V_{max} = maximum aircraft velocity.

The real drivers and their proxies, according to NAVAIR, are: quantity and complexity, proxied by airframe, (AF) and avionics (AV) cost; and environment, proxied by maximum velocity (V_{max}). The MFHBF of the aircraft is included as a real cost driver by assertion with no intuitive explanation.

b. The NAVAIR F-18 Subsystem Baseline Tracking Model

(1) Basic Form and Uses

The NAVAIR subsystem baseline tracking model calculates O&S costs in five cost categories for the twenty-three two-digit WUCs that define the F-18 at the subsystem level.[1] This model was implemented following DSARC II (December 1975) and is designed to permit NAVAIR to track changes from initial baselines over time in the costs of direct maintenance personnel; component rework; replenishment spares; other consumables; and POL.

The model is internal to NAVAIR, and each cost equation is sensitive to key design parameters that are reported to NAVAIR by MCAIR (the F-18 prime contractor). It provides NAVAIR with an in-house cost tracking capability that focuses on trends in the five O&S cost categories. It should be emphasized that the equations are not intended to provide absolute independent validations of the absolute values of O&S costs reported by MCAIR and subsequently reported to OSD through the DSARC process. The NAVAIR tracking equations are intended solely as

[1]The twenty-three WUCs and their nomenclatures are: WUC 11, airframe; WUC 12, fuselage compartments; WUC 13, landing gear; WUC 14, flight controls; WUC 24, auxiliary power unit; WUC 27, turbofan engine; WUC 29, power plant installation; WUC 41, environmental control system; WUC 42, electrical system; WUC 45, hydraulic system; WUC 46, fuel system; WUC 47, oxygen system; WUC 51, instruments; WUC 56, flight reference; WUC 57, internal guidance/flight control; WUC 63, UHF communications system; WUC 67, integrated COMM/NAV/IFF; WUC 72, radar navigation; WUC 73, bomb navigation; WUC 74, weapons control; WUC 75, weapons delivery, WUC 76, electronic countermeasures; WUC 91, emergency equipment.

barometers of trends from the initial baseline. A trend judged undesirable, or violent deviation from a trend, can serve as a signal that a particular design parameter requires management attention by both NAVAIR and MCAIR.

The five equations are simple algebraic statements that depend on given standard factors and design parameters that vary by WUC. The direct maintenance personnel equation is sensitive to changes in maintenance manhours per flying hour, and the POL equations is sensitive to gallons consumed per flying hour. The other three equations for component rework, replenishment spares, and other consumables, are sensitive to acquisition cost by WUC and mean flight hours between failures by WUC.

(2) The WUC-Level Baseline for Component Rework, Replenishment Spares, and Other Consumables

The three equations for component rework, replenishment spares, and other consumables, arrive at the two-digit WUC code level by taking F-4J 3M data for labor and material dollars per flying hour and constructing percentages of labor and material by WUC.[1] These percentages are then applied to the DSARC II values of component rework, replenishment spares, and other consumables calculated by the "total system model" regression equations and given in Table 6 earlier.[2] Once these DSARC II values are allocated to WUC based on the F-4J percentages, the allocated values are entered into the equations as WUC unique constants. These constants, based on the original DSARC II calculations and the F-4J experience, remain fixed throughout the useful life of the subsystem tracking model.

[1]The F-4J data were taken from the FY 3M RECAP report.

[2]The absolute values used in the subsystem tracking equations are actually rounded values of those listed in Table 8. Component rework is rounded to $300 per flying hour, and replenishment spares and other consumables are both rounded to $200 per flying hour.

Even if the total system calculated values change after DSARC II, as they are almost certain to do, the constants in the subsystem tracking equations for component rework, replenishment spares, and other consumables remain fixed on the original DSARC II O&S cost calculations and the F-4J allocation percentages. The rationale for this feature is that the subsystem tracking model is designed to reveal trends and deviations from trends, not absolute values. In order to permit a trend to be revealed over time, and for deviations early in the time period to be comparable in magnitude and direction to deviations later in the life of the full-scale engineering program, it is essential that the same baseline be maintained.

As an example of how the DSARC II cost calculations are allocated to F-18 WUC based on the F-4J 3M experience, we can examine component rework. The rounded DSARC II component rework cost per flying hour for the F-18 is $300. Labor and material costs of component rework for the F-4J by WUC are shown in Table 8. The F-4J percentages in the two columns under labor and material add to 100%. They represent the exhaustive categorizations of 3M-reported component rework dollars by labor and material for a particular time period (FY 74). Each of these percentages, multiplied times the F-18 DSARC II component rework cost of $300, yields the numbers in two columns of Table 8 labelled "portion of $300 allocated." These numbers are the portions of the total F-18 component rework allocated to each WUC.

The two-digit WUCs on the F-4J are identical to those on the F-18 with one exception, WUC 24, auxiliary power unit, so WUC 27 (turbofan engine) was used as a proxy for WUC 24 since

Table 8. F-4J COMPONENT REWORK ALLOCATION PERCENTAGES USED FOR THE F-18 SUB-SYSTEM TRACKING MODEL

WUC	Labor		Material	
	F-4J %[1]	Portion of $300 Allocated[2]	F-4J %[1]	Portion of $300 Allocated[2]
11	3.21	$ 9.63	1.53	$ 4.59
12	0.31	0.93	0.21	0.63
13	4.00	12.00	2.88	8.64
14	3.30	9.90	2.34	7.02
24	2.60	7.80	2.16	6.48
27	7.85	23.55	6.52	19.56
29	0.33	0.99	0.45	1.35
41	2.30	6.90	2.05	6.15
42	2.24	6.72	2.34	7.02
45	1.71	5.13	1.51	4.53
46	1.26	3.78	0.97	2.91
47	0.49	1.47	0.22	0.66
51	3.74	11.22	2.56	7.68
56	3.10	9.30	3.15	9.45
57	1.05	3.15	0.52	1.56
63	0.82	2.46	1.26	3.78
67	0.55	1.65	0.39	1.17
72	1.97	5.91	1.55	4.65
73	4.93	14.79	2.25	6.75
74	6.85	20.55	10.23	30.69
75	2.05	6.15	1.46	4.38
76	0.79	2.37	0.77	2.31
91	0.14	0.42	0.20	0.60

[1]The percentages in the two percentage columns add to 100%, indicating that the total component rework dollars on the F-4J were allocated exhaustively to the WUCs listed.

[2]The dollar amounts in the two dollar columns add to $300, the value of the DSARC II component rework calculation for the F-18, indicating that the total sum is allocated exhaustively to the WUCs listed.

Source: *F-18 Sub-System Operating and Support Cost Tracking Report, March 1977*, Naval Weapons Engineering Support Activity, Management Engineering Department, prepared for NAVAIR Logistics Management Division, Advanced Development Branch.

the maintenance and logistics characteristics of the two WUCs were deemed to be essentially the same by NAVAIR.[1]

Once the component rework DSARC II value was allocated to F-18 WUCs as shown in Table 8, these values were introduced into each WUC component rework equation as constant terms. There are twenty-three component rework equations, and each equation has a value for labor cost and material cost derived in the manner described above. As an example, the component rework cost tracking equation for WUC 72 (radar navigation) is

$$\$CR_{72} = \left[\$5.91 + \left(\$4.65\ \frac{UPC'}{UPC}\right)\right]\left(\frac{MFHBF}{MFHBF'}\right) FH\ .$$

where:

CR	=	component rework
UPC	=	baseline production cost by WUC
UPC'	=	latest update of production cost
MFHBF	=	baseline mean flight hours between failure
MFHBF'	=	latest update of MFHBF
FH	=	total flight hours for all aircraft.

Ignoring the other terms in the equation until the later detailed discussion of each cost category equation, it is the \$5.91 and the \$4.65 that are of interest. These are allocated values of labor component rework dollars (\$5.91) and material component rework dollars (\$4.65) that remain the same for all

[1]The allocation percentage for WUC 24 was developed by taking the F-4J WUC 27 percentage and multiplying it by a ratio of MMH/FH for WUC 24 and WUC 27. Thus,

$$\text{WUC } 24\% = \text{WUC } 27\%\ \frac{\text{WUC 24 MMH/FH.}}{\text{WUC 27 MMH/FH}}$$

The MMH/FH values were taken from MCAIR's 6 April 1976 report to NAVAIR. NAVAIR does not explain whether the WUC 24 labor and material percentages were deducted from WUC 27 to permit the total percentages to still add to 100%, or whether all WUC's were reduced proportionally to make up the WUC 24 percentages, or whether some other procedure was used.

calculations of component rework dollars for WUC 72 ($\$CR_{72}$). Thus, the baseline for component rework cost for the F-18 is firmly grounded in the initial DSARC II total system cost calculations. Deviations from the baseline will be caused by changes in the other terms in the equation, which, excluding flying hours (FH), NAVAIR offers as design sensitive. This will be explored more completely in the later equation discussions.

The procedure for the other WUCs is the same as for WUC 72. Constants taken from the allocated values in Table 8 are entered in each WUC component rework equation.

Similar allocations of DSARC II total system calculations are made to all twenty-three WUCs for replenishment spares and other consumables. Again, F-4J data are used to construct the percentages, then these percentages are multiplied times the DSARC II calculated values for replenishment spares (\$200/FH) and other consumables (\$200/FH). These values are then entered as constants into their respective WUC equations. The only difference is that the percentages for replenishment spares and other consumables are not broken out by labor and material as they are for component rework.

(3) <u>Direct Maintenance Personnel Cost Equation</u>

This cost is defined as the cost of enlisted squadron level operating and maintenance personnel at both the organization and intermediate levels of maintenance. The equation is

$$\$DMP = \left(\frac{\$/AC/YR}{MMH/FH}\right)\left(\frac{MMH}{FH}\right)\left(\# \text{ AC} - \text{YRs}\right)$$

where:

DMP = direct maintenance personnel cost

\$/AC/YR = dollars per aircraft per year

MMH/FH = maintenance manhours per flying hour

#AC-YRs = total number of aircraft for total number of years in operation.

The direct maintenance personnel cost ($DMP) is equal to the baseline value of maintenance personnel cost for a given MMH/FH, the term $\frac{\$/AC/YR}{MMH/FH}$, times the latest reported MMH/FH, times the total number of aircraft for the total number of years they will be in operation. This equation is awkwardly laid out because the MMH/FH seems to appear twice and in fact seems to cancel itself out.[1] A clear presentation would indicate that the MMH/FH in the first expression is the baseline initial estimate, while the MMH/FH in the second expression is the current reported update of MMH/FH. Rewriting the equation for clarity it might appear as

$$\$DMP = \$/AC/YR \ \frac{MMH/FH'}{MMH/FH} \times \#AC(YRs)$$

where maintenance manhours per flying hour prime MMH/FH' is the current update, and MMH/FH is the initial baseline estimate. Rearranged this way, it is easier to see that if the current update of MMH/FH' is greater than the initial MMH/FH, then the $DMP will rise. If MMH/FH' were always the same as the original baseline MMH/FH, then $DMP would stay at the baseline value.

The term "number of aircraft for given years" (#AC-YRs) is fixed at 7609 for all WUCs.

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[1]The discussion in the subsystem model manual (March 1977) makes an error that adds to the confusion in initially understanding the equation. The error is the statment that the term $\frac{\$/AC/YR}{MMH/FH}$ "...is a constant cost factor whose value is 7325 for all two-digit work unit codes and is based upon $17.44/MMH and 35 FH/MO/AC...." In fact, the top part of the term $/AC/YR is equal to $7325, and this is the same for all WUCs on the assumption, stated in the manual, that dollars per maintenance manhour equal $17.44, and that the number of flight hours per year per aircraft equal 420 (35 per month). Now, for each WUC there is a separate MMH/FH baseline estimate, and applying this to the expression generates a baseline value that is unique to that WUC. It is against this baseline value that the new estimate of MMH/FH will have an impact.

(4) Component Rework Equation

The component rework equation is

$$\$CR = \left[(\$LAB) + \left(\$MAT\ \frac{UPC'}{UPC}\right)\right]\left(\frac{MFHBF}{MFHBF'}\right)(FH)$$

where:

$CR	=	component rework dollars
$LAB	=	baseline allocation of $300 DSARC II labor estimate by WUC
$MAT	=	baseline allocation of $300 DSARC II materials estimate by WUC
UPC	=	baseline production cost by WUC
UPC'	=	latest update of production cost by WUC
MFHBF	=	baseline mean flight hours between failure by WUC
MFHBF'	=	latest update of mean flight hours between failure by WUC
FH	=	total flight hours for all aircraft for full life cycle = constant = 2,629,670.

The equation is intended to capture the cost of repairing repairable components at the depot including scheduled and unscheduled arrivals. Complexity, operational environment, and failure rates are identified as the real cost drivers. Unit production cost (UPC) is a proxy for complexity and operational environment, and mean flight hours between failure is a proxy for scheduled and unscheduled depot arrivals.

The sensitivities of the equation are that $CR rises as UPC rises above the baseline value and as the MFHBF grows shorter than the baseline time period.

A separate equation is set up and exercised for each WUC and for each update of all UPCs and MFHBFs.

(5) Replenishment Spares Equation

The replenishment spares equation is

$$\$RS = (\text{REPBASE}) \ \frac{\text{UPC}'}{\text{UPC}} \ \frac{\text{MFHBF}}{\text{MFHBF}'} \ (\text{FH})$$

where:

\$RS	= rep spares costs
REP BASE	= allocation of \$200 DSARC II estimate by WUC
UPC	= baseline production cost by WUC
UPC'	= latest update of production cost by WUC
MFHBF	= baseline mean flight hours between failure by WUC
MFHBF'	= latest update of mean flight hours between failure by WUC
FH	= constant = 2,629,670.[1]

The equation is written to capture the cost of repairable components required to replace items which are beyond economical repair at the maintenance levels. It is the same equation as for component rework, with a slight difference in the REP BASE item. The DSARC II baseline cost is not broken into labor and material as it is for component rework; instead it is allocated as a lump sum called REP BASE.[2] The sensitivities are the same as for component rework.

(6) Other Consumables Equation

The other consumables equation is

$$\$OC = (\text{OTHER BASE}) \left(\frac{\text{UPC}'}{\text{UPC}}\right)\left(\frac{\text{MFHBF}}{\text{MFHBF}'}\right) (\text{FH})$$

where:

\$OC = other consumables dollars

[1]See explanation of constant in previous section on component rework equation.

[2]See earlier discussion in Section b.

OTHER BASE	=	allocation of $200 DSARC II estimate by WUC
UPC	=	baseline production cost by WUC, from MCAIR
UPC'	=	latest update of production cost by WUC from MCAIR
MFHBF	=	baseline mean flight hours between failure by WUC from MCAIR
MFHBF'	=	latest update by WUC from MCAIR
FH	=	constant = 2,269,270.[1]

$OC is the cost of operating consumables which are non-repairable materials used in organization and intermediate maintenance and repair of repairables. It is the same equation as for component rework and rep spares. Like rep spares, the DSARC II baseline cost is not broken into labor and material as it is for component rework; instead it is allocated as a lump sum called OTHER BASE.[2]

(7) POL

POL cost is based on engineering performance data and is calculated only for WUC's 11 (airframe) and 27 (turbofan engine).

(8) Using the Baseline System Before DSARC II

This baseline subsystem tracking model is currently used in the F-18 program as a post-DSARC II indicator of sudden or persistent changes in component O&S costs; however, its methodology could be applied to O&S cost estimates before DSARC II and perhaps even as early as DSARC I.

As a costing exercise to develop a reasonable approximation of future O&S costs during the conceptual phase between

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[1]See explanation of constant in previous section on component rework equation.

[2]See earlier discussion in Section b.

DSARC 0 and DSARC I, the methodology could provide O&S costs by two-digit WUCs. This would create the potential to assess high O&S cost equipments during the conceptual stage of weapon system definition, and offer the opportunity to make trade-offs between high cost equipments and performance or design characteristics of the aircraft.

As a system definition exercise, the methodology would permit a proposed aircraft to be built system by system and costed for O&S. A cost target could be derived through this process, or a cost target exogenously determined could be worked against to develop alternative sets of equipments that would be consistent with the target.

The methodology as applied in the F-18 case requires the following:

(1) acquisition cost estimates to be used as inputs in the total system model equations;

(2) physical characteristics of the aircraft to be used as inputs into the equations;

(3) a reference aircraft for which cost data are available by two-digit WUC, and these data are used to construct percentages of cost by WUC, which then serve as the allocation factors to distribute the parametrically estimated total O&S costs to the individual WUC equipments.

This methodology could be tailored more narrowly than an entire reference aircraft. Each two-digit WUC equipment could be selected from a different aircraft if the equipments on different aircraft were more analogous to the proposed systems than the equipments on a single aircraft. Allocation factors based on analogous WUC equipments instead of entire aircraft should offer closer approximation of the new systems.

The F-18 application of this methodology is based on PPBS data thorugh the Navy Resources Model (NARM), but the methodology is generally applicable to other data. The new NALCOMIS O&S Maintenance Subsystem (MS) Report, discussed later in this

chapter, provides support cost data by Type/Model/Series aircraft at the seven-digit WUC level of detail. Total system parametric equations based on these data and allocated to WUCs according to the experience data contained in the MS Report could provide an application of the baseline tracking methodology that relys on actual maintenance action reporting systems. This possibility is discussed in greater detail in Chapter IV.

c. The MCAIR F-18 Subsystem O&S Model

(1) Basic Form and Uses

The MCAIR subsystem O&S model is based on a detailed equipment level approach that uses the basic techniques employed in the Navy level of repair analyses (LORA) models.[1] It was submitted to NAVAIR for approval more than a year after DSARC II. It combines key elements of reliability, maintainability, unit pricing information, and Navy operational factors to compute logistics support costs (LSC) by major equipment. As the F-18 moves through the testing program, the model's outputs will be compared with test data as a verification procedure.

Table 9 displays a typical LSC format for the model outputs proposed by MCAIR. For each work unit code on the aircraft, including those broadly identified as "avionics" (WUC's 51-76), LSC costs will be:

(1) Organizational maintenance labor and material (repairable and consumable) dollars;

(2) Intermediate maintenance labor and material (repairable and consumable) dollars;

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[1]MIL-STD-1390 B (NAVY), 1 December 1976, defines level of repair analyses (LORA) as a justification of the decision to repair or discard a failed item of hardware for each anticipated maintenance action on the item. This justification is required to support the decision to repair at any maintenance level. Repair of an item is removal and replacement of a failed lower indenture assembly, to include fault verification of the item, fault isolation and replacement of the failed lower assembly, and item test.

Table 9. TYPICAL MCAIR O&S SUBSYSTEM LSC COST SUMMARY FORMAT

Work Unit Code (WUC)	Maintenance Dollar Costs									Spares Dollar Cost		Other Dollar Costs*
	Organizational			Intermediate			Depot					
	Labor	Material		Labor	Material		Labor	Material		Rep Spares	Initial Spares	
		Repair	Consum		Repair	Consum		Repair	Consum			
11												
12												
13												
14												
24												
27												
29												
41												
42												
45												
46												
47												
51												
56												
57												
63												
67												
72												
73												
74												
75												
76												
91												

*Other costs include administration, packaging, handling, and transportation.

Source: McDonnell Aircraft Company, *Life Cycle Cost*, Report No. MDC A4041, 6 February 1976.

(3) Depot maintenance labor and material (repairable and consumable) dollars;

(4) Initial spares dollars;

(5) Replenishment spares dollars;

(6) "Other," including packing, handling, storage, transportation, and administration dollars.

(2) Structural Flow of Model

The structuring of the model begins with the Navy's operational concept contained in the Weapon System Planning Document (WSPD).[1] Based on the operational concept, maintenance demands (removals, repairs) by WUC are estimated and used to establish operational factors including turnarounds and order-and-ship times. A level of repair analysis is then conducted which generates the Source, Maintenance, and Recoverability (SMR) codes that identify each piece of equipment according to,

(1) source codes, assigned to support items such as spares, repair parts, component parts, kits, special tools, test equipment, and ground support equipment, to identify the manner of acquiring items for maintenance, repair, or overhaul;

(2) maintenance codes, assigned to support items to identify the maintenance levels authorized to remove and replace, repair, overhaul, assemble, inspect and test, and condemn items;

(3) recoverability codes, assigned to support items to indicate to maintenance and supply personnnel the reclamation or disposition action required for items that are removed and replaced during maintenance.

[1]The WSPD is a Chief of Naval Operations (CNO) document that contains planning information for the initial introduction of new weapon systems. It is a basic policy and planning document published by NAVAIR designed to provide approved CNO/CMC/NAVAIR planning for: base loadings, procurements, delivery schedules, system inventories, planning factors including flying hours and authorized operating service life, material support policy including spare parts support and level of repair, training plans, and other pertinent planning information.

The SMR codes for equipment, combined with projected maintenance demands and operational factors, lead to an estimate of maintenance flows (organizational, intermediate, Naval Air Rework Facility, vender), and these flows permit an estimate to be made of direct maintenance costs for labor and materials at three levels of maintenance. Initial spares requirements are determined based on the previously established operational factors (turnarounds, order-and-ship times, etc.), and replenishments spares are generated based on maintenance flows-maintenance cost projections. The indirect costs of spares (administration, transportation, packing, facilities, other) are determined based on the initial and rep spares estimates, and these are then distributed along with maintenance and spares costs against WUCs to produce the O&S costs estimates.

d. CASEE Simulation Model

The Carrier Aircraft Support Effectiveness Evaluation (CASEE) model is a simulation aircraft maintenance technique to provide outputs that focus on squadron readiness. Input requirements are large and include aircraft and two-digit WUC reliability and maintainability characteristics, unscheduled maintenance activity, scheduled maintenance, and the spares and resupply flow. The kinds of data inputs into CASEE include: total sorties scheduled and flown, flight hours, maintenance manhours per flight hour, maintenance actions by WUC, failures by WUC, organizational level manhours per maintenance action, and aircraft turnaround time.

During the conceptual phase of a proposed weapon system, CASEE generates estimated performance data and proposed support concepts and operational requirements alternatives. During DSARC II additional estimates are generated.

By varying subsystem reliability, subystem maintainability, spares provisioning and level of repair, the effects on maintenance

manhours per flying hour and maintenance actions by WUC can be derived. Also developed by varying reliability and maintainability are the effects on maintenance manhours by WUC for each maintenance action.

The potential of CASEE as a discriminator among alternative systems is high. It produces logistics data when certain characteristics are varied for individual equipments.

The data inputs to CASEE are:

(1) Squadron complement by aircraft type,
(2) Aircraft system and subsystem R&M data,
(3) Mission flights,
(4) Post-mission activities,
(5) Unscheduled maintenance,
(6) Spares and resupply chain,
(7) Scheduled maintenance.

The outputs based on these data are:

(1) Total sorties scheduled,
(2) Total sorties flown,
(3) Total flight hours,
(4) Overall squadron readiness,
(5) Number of operationally ready and full systems capability (FSC) aircraft at beginning of each flying day,
(6) Total not operationally ready (NOR) hours and percent by NOR category,
(7) Total reduced material category condition (RMC) percent and hours by RMC category,
(8) Maintenance manhours/flight hour,
(9) Number of ground aborts,
(10) Number of inflight aborts,
(11) Maintenance actions by work unit code,
(12) Failures by work unit code (WUC),
(13) Bit--Detected failures by WUC,

(14) Manhours/maintenance action by WUC (organizational level),

(15) Manhours/maintenance action by WUC (intermediate level),

(16) Work center utilization,

(17) Work center queing,

(18) Parts delay by WUC,

(19) Turnaround time--aircraft recovered "up,"

(20) Turnaround time--aircraft recovered "down," or aborted during preflight inspection.

e. Equipment Life Cycle Cost Model

The Naval Material Command's equipment life cycle cost (ELCC) model is similar to the AFLC LSC accounting model in that a large number of input variables (104) are combined through simple algebraic equations to produce equipment level costs.[1] The major difference between the two models is that the ELCC model is intended for total LCC coverage while the LSC focuses entirely on ten cost elements for logistic support. The ELCC model has been used after DSARC II but before DSARC III.

The ELCC model has three broad LCC categories: research and development, investment, and operating and support. These cost elements are divided into eighty-five sub-cost elements, sixty-one of which comprise the basic questions. The basic equations are composed of one hundred and four variables. Each equation belongs to one of the cost categories and funding types listed in Table 10.

The model produces thirteen reports at different levels of detail. These reports are listed in Table 11.

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[1]Naval Weapons Engineering Support Activity, Management Engineering Department, Cost Management Division, is the custodian of the model. It is presented in a *Life Cycle Cost Guide for Equipment Analysis*, January 1977.

Table 10. NAVY EQUIPMENT LIFE CYCLE COST MODEL COST CATEGORIES AND FUNDING TYPES

Cost Categories	Funding Type
Contractor Payment	Research and Development
Program Management	Procurement
Testing	Construction
Prime Equipment	Operation and Maintenance
Training	Military Personnel
Supply Support	Others
Technical Data	
Support Equipment	
Operation	
Maintenance	

Table 11. NAVY EQUIPMENT LIFE CYCLE COST MODEL REPORTS

Input Data Reports	Output Data Reports
Equations	Summary
Remarks	Funding by Cost Category
Dictionary	Cost Breakdown by Year
Variable Values	Cost Breakdown Totals
Cost Adjustment Factors	General Funding
	Annual Cost by Funding Type
	Annual Cost by Cost Category
	Sensitivity Analysis

The computer program developed for the ELCC model provides the analyst with the flexibility to modify the standard model to fit specific project needs. If desired, the user of the model can redefine the entire cost structure. This flexibility means that the ELCC model is a basic framework around which equipment level life cycle costs can be structured. The one hundred and four equation variables and the sixty-one equations are presented in Appendixes F and G.

The sixty-one operating and support equations are simple algebraic models for calculating sixty-one of the eighty-five sub-cost elements under the three broad LCC elements (research and development, investment, operating and support). The operating and support cost elements are given in Table 12 and, for each O&S element followed by a "yes" in the "equation to calculate" column, there is a separate equation in the model. Each of the "no" entries represents a summation of calculated equations' values.

Data for the 104 variables in the ELCC model are provided through the system project office, the contractor, and the logistic support organization. The Project Management Office, Air, (PMA) will provide system operations, acquisition costs, project schedules, and contractual-related data. The contractor is responsible for the inherent design characteristics data. The integrated logistic support manager has access to data on maintenance, personnel and training, technical data, and other pertinent data.

4. DATA AND MANAGEMENT SYSTEMS

a. The Naval Air Logistics Command Management Information System

The Naval Air Logistics Command Management Information System (NALCOMIS) - Operating and Support (O&S) Visibility of Management and Support Costs (VAMOSC) Management Information

Table 12. EQUIPMENT LIFE CYCLE COST MODEL OPERATING AND SUPPORT COST ELEMENTS

ELCC O&S COST ELEMENTS	Equation to Calculate
OPERATING	No*
Operating Personnel	Yes
Operating Facilities	Yes
Operating Energy Consumption	Yes
Operating Material Consumption	Yes
Operating Software Maintenance	Yes
SUPPORT	No*
Corrective Maintenance Labor	No*
Org-Int Level Remove and Replace	Yes
Org-Int Level Repair	Yes
Depot Repair	Yes
Repair Material	Yes
Transportation and Packaging	Yes
Preventive Maintenance	No*
Labor	Yes
Material	Yes
Overhaul	No*
Labor	Yes
Material	Yes
Transportation	Yes
Support and Test Equipment Maint.	Yes
Facilities	Yes
Documentation Maintenance	Yes
Supply Support	No*
Replenishment Spares	Yes
Supply System Management	Yes
Training	No*
Operator	Yes
Org-Int Level Maintenance	Yes
Depot Level Maintenance	Yes

*Add-up of elements.

System accumulates data from various sources to produce three basic reports--The Total Support System (TSS) report, the Maintenance Subsystem (MS) report, and the Maintenance Subsystem detail (MSD) report. Together these reports contain the operating and support costs of Navy and Marine aircraft weapon systems by Type/Model/Series (TMS) for a complete fiscal year. Samples of these reports are presented in Appendixes H (TSS) and I (MSS and MSD).

There are two important distinctions between the TSS and the MS and MSD reports. The first is that the TSS reports cost data at the total TMS weapon system level only, while the MS and MSD report cost data at the component level by TMS. The second distinction is that the TSS cost data are based on budget data, while the MS and MSD costs are based on production accounting reports at organization, intermediate, and depot maintenance activities.

b. The TSS Report

All aircraft TMS that had either 100 or less flying hours or contained 3 or less aircraft during the fiscal year are listed together in a miscellaneous data set at the end of the TSS report. Aggregations for all aircraft are also listed in a grand summary data set at the end of the report. The remainder of the report consists of four data pages for each TMS with the data arranged into cost elements for organizational support, intermediate support, depot support, training support, recurring investment, and other costs. These costs are available by major claimants such as PACFLT, LANTFLT, NET, MARINE, RESERVE, NAVAIR, OPNAV, NAVEUR, and MISC. Table 13 displays the cost elements and identifies the sources of the data which fill them. The data systems rely heavily on budget and accounting data.

Table 13. COST ELEMENTS AND DATA SOURCES IN THE NAVY VAMOSC-AIR TSS REPORT

Cost Element	Data Source
ORGANIZATIONAL COSTS	
Personnel: military, civilian, contract	NCIS/OPS [1]
Temporary additional duty	NCIS/OPS [1]
Training expendable stores	SPCC/CAMIS [2]
Maintenance supply	OP-51 [3]
Personnel support supplies	OP-51 [3]
POL	OP-51 [3]
Organizational Subtotal	
INTERMEDIATE COSTS	
Maintenance supplies	OP-51 [3]
Personnel: military, civilian, contract	NCIS/OPS [1]
Intermediate Subtotal	
DEPOT COSTS	
Aircraft rework	AIR-414 [4]
Engine rework	AIR-414 [4]
Component rework	AIR-414 [4]
Other rework	AIR-414 [4]
Depot Subtotal	
TRAINING COSTS	
Fleet readiness squadrons personnel: military, civilian, contract	NCIS/OPS [1]
FRS temporary additional duty	NSIC/OPS [1]
FRS training expendable stores	SPCC/CAMIS [2]
FRS maintenance supplies	OP-51 [3]
FRS personnel support supplies	OP-51 [3]
FRS POL	OP-51 [3]
FRS Subtotal	
O&M Training Subtotal	
Operational training devices (simulators)	FASOTRAGRULANT [5] & FASOTRAGRUPAC [5]
Maintenance Training	CNET [6]
All Training Support Subtotal	
RECURRING INVESTMENT	
Replacement repairables	NADC [7]
Modifications	AIR-01A6 [8]
Recurring Investment Subtotal	
OTHER FUNCTIONS	
NETS	NASEU [9]
CETS	NASEU [9]
Publications	NATSF [10]
Other Functions Subtotal	
GRAND TOTAL FOR ALL PREVIOUS COST ELEMENTS	

[1] Navy Cost Information System/Operations Subsystem.

[2] Ships Parts Control Center/Conventional Ammunition Integrated Management System.

[3] Deputy Chief of Naval Operations, Air Warfare, Aviation Programs Division.

[4] Naval Air Systems Command, Logistics Management Division, Depot Management.

[5] Fleet Air Support Organization Training Group, - Atlantic, Pacific.

[6] Chief of Naval Education and Training.

[7] Naval Air Development Center.

[8] Naval Air Systems Command, Plans and Program Office, Configuration Management Office.

[9] Naval Aviation Engineering Service Unit.

[10] Naval Air Technical Services Facility.

The categories are explained as follows:

(1) Personnel costs. The organization level personnel costs in Table 13 under the first subcategory (personnel; military, civilian, contract) are the costs attributable to flight operations.

(2) Maintenance supplies. This category represents the costs of repair parts for organizational level maintenance under the organizational heading and the costs of repair parts for intermediate maintenance under the intermediate heading. The repair parts for Fleet Readiness Squadrons (FRS) are listed separately under the training support heading in Table 5.

(3) Aircraft rework. The maintenance costs for aircraft rework purchased from organizations within DoD and from commercial organizations are listed here.

(4) Engine rework. The maintenance costs for engine rework purchased from organizations within DoD and from commercial organizations are listed here.

(5) Component rework. The maintenance costs for component rework purchased from organizations within DoD and from commercial organizations are listed here.

(6) Other rework. The costs included in this element are for all hardware-oriented programs not included in the aircraft, engine, and component rework categories, and other engineering support which includes the costs of engineering efforts in the Cognizant Field Activity (CFA) program.

(7) Replacement repairables. This is the cost of replacements for repairable components that are required to maintain adequate inventory.

(8) Modifications. This category displays the procurement costs of modifications required by a specific TMS. Included are the associated logistic support investment costs and nonrecurring engineering costs as well as the recurring kit costs.

c. The MS Summary Report

The MS report presents a summary of component maintenance and support costs by TMS, with scheduled and unscheduled maintenance costs displayed at the organizational, intermediate, and

depot levels. There is one page for each TMS aircraft, with costs of labor and consumables associated with the maintenance actions on the WUC equipments. The data sources are the 3M system, NARF data bases, and ASO contract data inputs. According to the MS report introduction, NADC has incorporated "statistical adjustments" intended to minimize the problems associated with multi-source data bases and inconsistencies in source data reporting. Some of these inconsistencies are a reference to criticisms of 3M data, and the adjustments are the NADC "ideal squadron" adjustment factor.[1] Because of the statistical adjustments, the MS report narrative advises that "...the costs generated in this manner may not be directly comparable at this time with related cost elements in the TSS." Whether these costs in the MS report will ever be directly comparable with the costs in the TSS report is unknown. Table 14 below presents the MS report cost elements.

The categories are explained as follows:

(1) Maintenance. The maintenance category for organization and intermediate in Table 11 consists of the resources utilized in the performance of separately identifiable scheduled and unscheduled maintenance actions reported on the 3M Maintenance Action Form (MAF).

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[1]Because there is much criticism and generally accepted "conventional wisdom" that 3M data reporting is uneven and unreliable, the MS attempts to adjust for these possibilities. Good squadron reporters are selected to determine average costs that will be applied to all squadrons. The selection of these good squadrons is a very sophisticated process, and it amounts to a series of rules by which squadrons are identified as bad reporters and are thereby eliminated from the average cost calculations for labor and consumables. There are two measures of flight activity reported to NADC, one is the daily flight summary by tail number on the 76-card, the other is the monthly squadron summary also reported by tail number and on the 79-card. One way to measure "good reporting squadrons" is the consistency between the total of the daily flight-summary cards for over a month and the total reported on the monthly squadron summary. NADC does not accept a squadron's data if there is a 20 percent or more variation in the summaries. Generally, by the end of the fiscal year the data can be reconciled and accepted.

Table 14. COST ELEMENTS IN THE NAVY VAMOSC-AIR MS REPORTS

Level of Detail	Cost Categories
Organization costs at 2-digit Work Unit Code Level of Detail	MAINTENANCE Labor scheduled Labor unscheduled Consumables scheduled Consumables unscheduled SUPPORT LABOR TECHNICAL DIRECTIVE COMPLIANCE LABOR
Intermediate costs at 2-digit Work Unit Code Level of Detail	MAINTENANCE Labor scheduled Labor unscheduled Consumables scheduled Consumables unscheduled SUPPORT LABOR TECHNICAL DIRECTIVE COMPLIANCE LABOR ATTRITION
Depot costs at 2-digit Work Unit Code Level of Detail	COMPONENT REPAIR ACTIONS NARF Direct labor Indirect Labor Material Commercial SURVEYED REPAIRABLES TECHNICAL DIRECTIVE COMPLIANCE LABOR
Costs reported only as sums for entire aircraft, not for each 2-digit Work Unit Code	PRE-EXPENDED MATERIAL ORGANIZATIONAL SUPPORT LABOR TECHNICAL DIRECTIVE COMPLIANCE MATERIAL COSTS Organization Intermediate Depot

(2) Labor scheduled. The costs for direct labor for preplanned maintenance actions as reported on the MAF and the associated portion of maintenance personnel salaries identified for each applicable WUC are carried here under organization and intermediate maintenance in Table 14.

(3) Labor unscheduled. This category is explained the same as the labor scheduled category above, except for maintenance actions other than scheduled.

(4) Consumables scheduled. This is the cost of Navy Stock Fund (NSF) repair parts used to perform scheduled maintenance, both at the organization and intermediate levels.

(5) Consumables unscheduled. This is the cost of NSF repair parts at organization and intermediate levels used to perform maintenance actions other than scheduled.

(6) Support labor. This is the direct labor reported on the 3M SAF (Support Action Form) for organization and intermediate levels.

(7) Technical directive compliance labor. The direct labor as reported on the 3M TDC (technical directive compliance) form is entered here for the organization and intermediate levels in Table 14.

(8) Attrition. Under the intermediate level in Table 14, this category is the replacement value of normally repairable components of a given TMS which are found to be beyond the point of economical repair at the intermediate level. It is based on actual unit replacement costs and actual fiscal year attrition, not on expenditures since all items are not necessarily replaced within a given fiscal year.

(9) Depot. This category is based on actual Beyond Capability of Maintenance (BCM) actions at the intermediate level; not all BCMs are reworked at the depot within a given fiscal year.

(10) Component repair actions. This consists of the costs reported to ASO of the direct labor, indirect labor, material costs associated with reworking enough components, for each WUC, to replace not-ready-for-issue components sent to the depot by intermediate level BCM actions. The cost for a given WUC is obtained from the average rework cost for the WUC and the BCM rate for the WUC.

(11) Direct labor. This category under NARF component repair actions in Table 14 is the direct labor associated with reworking components reported by intermediate level BCM actions.

(12) Indirect labor. This category under NARF in Table 14 is the overhead indirect labor associated with reworking components reported by intermediate BCM actions.

(13) Surveyed repairables. This is the replacement value of normally repairable components which are found to be beyond the point of economical repair at the depot level, and is based on actual repair/survey rates.

As a check on the consistency between the TSS and the MS, we computed maintenance cost per flying hour for six TMS aircraft from both the TSS and the MS.

As can be seen in Tables 15, 16, and 17 below, the following statements are substantiated for this sample of TMS depot component repair costs per flying hour:

(1) The rankings of low to high cost TMS are considerably different in the two reports for the six TMS examined.

(2) The absolute dollar differences for any one TMS between the TSS and MS costs are considerable.

(3) The percentage differences between TSS and MS costs are not consistent for all TMS; that is, for some TMS the MS cost is greater than TSS cost, for others the reverse is observed.

d. The MSD Report

The MSD report is produced for each TMS aircraft and comprises 22 pages of maintenance subsystem data. It is the detail backup for the MS summary report. The first page of the report is identical to the single page for that particular TMS aircraft that appears in the MS report described above. The subsequent pages of the MSD report are additional detail that lie behind the single summary page, as well as maintenance data that are not summarized on the summary page. The acronym MSD was created to distinguish this detailed report from the summary MS report. In fact, the Navy classes both reports the MS report. Owing to

Table 15. COMPARISON OF SIX TMS AIRCRAFT DEPOT COMPONENT MAINTENANCE COST PER FLYING HOUR RANKINGS IN TSS AND MS FOR FY 75 DATA FROM 1976 VAMOSC-AIR

TMS	MS Rank*	TSS Rank*
F-8H	1	3
F-4N	2	4
F-4B	3	6
F-8J	4	2
F-4K	5	5
F-8K	6	1

*In each column, rank 1 is lowest cost, rank 6 is highest.

Table 16. DEPOT COMPONENT MAINTENANCE COSTS (DCMC) AND FLYING HOURS (FH) FOR SIX TMS AIRCRAFT IN THE TSS AND MS FOR FY 75 (1976 VAMOSC-AIR)

TMS	MS DCMC	TSS DCMC	Flying Hours	MS $/FH	TSS $/FH
F-4B	$ 3,123,000	$ 4,587,000	17708	$176	$259
F-4J	16,672,000	14,981,000	85695	194	174
F-4N	4,348,000	5,104,000	31625	137	161
F-8H	1,183,000	1,330,000	9448	125	140
F-8J	2,476,000	1,859,000	13817	179	134
F-8K	727,000	317,000	3597	202	88

Table 17. PERCENTAGE DIFFERENCES BETWEEN DEPOT COMPONENT MAINTENANCE COSTS (DCMC) FOR SIX TMS AIRCRAFT IN THE TSS AND MS FOR FY 75 DATA (1976 VAMOSC-AIR)

TMS	TSS DCMC as a Percent of MS DCMC
F-4B	146
F-4J	89
F-4N	117
F-8H	112
F-8J	75
F-8K	43

possible confusion, IDA added the D for "detail" to distinguish between the MS summary report and the detailed reports that are available for each TMS aircraft.

The cost categories on the first data page in the MSD report for any given TMS aircraft are identical to the categories presented in Table 14 for the MS report.

The next data format presents cost categories for unscheduled maintenance actions by WUC, and these categories are shown in Table 18.

A summary page following the data format shown in Table 18 contains

(1) Aircraft totals derived by summing across all WUCs for the categories in Table 18;

(2) percentage contribution of each cost type to total costs;

(3) percentage contribtuion to each cost type by major subsystem (airframe, power plant, and avionics);

(4) maintenance level cost summary for material and labor ($K);

(5) flight hour summary;

Table 18. UNSCHEDULED COMPONENT MAINTENANCE COST CATEGORIES IN THE MSD REPORT

MATERIAL COSTS BY WUC
Material cost for organizational level repairs Material cost for intermediate level repairs Cost of intermediate level attritions Material costs of depot level repairs (Depot-NARF, Commercial) Cost of depot level surveys Total material cost for all maintenance levels
DIRECT LABOR COST BY WUC
Labor costs at organizational level (maintenance hours) Labor costs at intermediate level (maintenance hours) Labor costs at depot level (NARF maintenance hours, Comm. maint. hours) Total direct labor cost for all maintenance levels
TOTAL COST - SUM OF ALL MATERIAL AND DIRECT LABOR COSTS FOR EACH WUC
MAINTENANCE COST PER FAILURE BY WUC
MEAN TIME (FLIGHT HOURS) BETWEEN FAILURES
MEAN TIME (FLIGHT HOURS) BETWEEN MAINTENANCE ACTIONS

(6) cost per flight hour and maintenance actions per flight hour;

(7) cost per program aircraft; operating aircraft.

A similar data page containing the cost categories in Table 18 is in the MSD report for scheduled componente maintenance actions, and it is followed by a similar page of additional summary data as listed in items 1 through 7 above.

The next data format in the MSD report is the Maintenance Action Report, and it contains maintenance frequency data broken down by type of maintenance actions and WUC for unscheduled maintenance. This is followed by a similar Maintenance Action Report format for scheduled maintenance.

A component manhour report is the next data format in the MSD report, and it summarizes manhour utilization by WUC.

A total material cost report is the next data format, and it is based on material issue data from a selected group of squadrons known to have good reporting practices. It is used to calculate the average material costs presented in the next data format, the Average Component Cost Report.

The Average Component Cost Report is based on several cost algorithms, and these are used to calculate the costs per action for each WUC. For each WUC on the TMS aircraft covered by a particular MSD report, the following costs per action are calculated, as shown in Table 19.

The distinctive characteristic to remember about the substantial detail described above for the various data formats in the MSD report is that this detail is available for approximately 100 TMS aircraft in the Navy. Thus, the same 22 pages of data formats as described above are available for each of the 100-plus aircraft TMS.

Most of the data formats discussed in the MSD report presentation above are available, according to the narrative in

Table 19. AVERAGE COST REPORT COST CATEGORIES IN THE MSD REPORT

MATERIAL COST PER ACTION BASIS
Consumable material cost for organizational level repairs
Consumable material cost for intermediate level repairs
Cost of intermediate level attritions
Material cost of NARF repair
Material cost of commercial repair
Material cost of depot surveys
LABOR (DEPOT ONLY)
Direct labor - NARF repair
Direct labor - Commercial repair
Indirect labor - NARF repair
DIRECT LABOR RATE

the MSD report, at the 7-digit WUC level through NADC. The 2-digit data shown in the regularly recurring MSD report are identified as summaries of the 7-digit data.[1]

e. <u>The Linkage Between Intermediate and Depot Maintenance in the MS and MSD Reports</u>

The real sophistication in the MS and MDS systems is the linkage between intermediate and depot maintenance. It is sophisticated because it solves the problem created by the absence of WUCs in the depot level maintenance reporting. WUCs are used at the organizational and intermediate levels. Figure 8 shows the linkage.

In Step 1, the repairable item data file (RIDF) maintained at Maintenance Support Office (MSO)[2], Mechanicsburg, PA, records Beyond Capability of Maintenance (BCM) items from the intermediate level, and each item is coded by WUC and part number.

In Step 2, the MSO part number file is used to assign each part-numbered item in the 3M RIDF a National Item Identification

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[1]The exceptions to the 7-digit availability are the following:

Support costs (painting, washing A/C, etc.) reported in the support action file. Support costs are allocated to the 7th WUC digit but reported only to the 2nd digit. In avionics there are practically no support costs.

Technical Directive Compliance (TDC) actions are reported only by 2-digit WUC. Manhours are reported and some materials. The materials cannot be allocated by WUC. The costs of TDC kits are not in the VAMOSC system because these are not reported in 3M.

Preexpendable Costs cover nuts- and bolts-type materials (bench stock). These costs are not separately identified.

[2]MSO maintains a depot cost library file to be used in developing depot cost data. Data in the file comes from two sources: (1) The NARFs, based on their production files, report by NIIN the numbers of items repaired and their costs; (2) the Aviation Support Office in Philadelphia reviews their contract files and extracts the number of NIINs worked on in contract maintenance and cost per NIIN. Costs differ between organic and contract maintenance. Often it is not possible to determine whether a given BCM item shown by WUC will be repaired in organic or contract facilities. In these instances NADC uses algorithms based on historical experience.

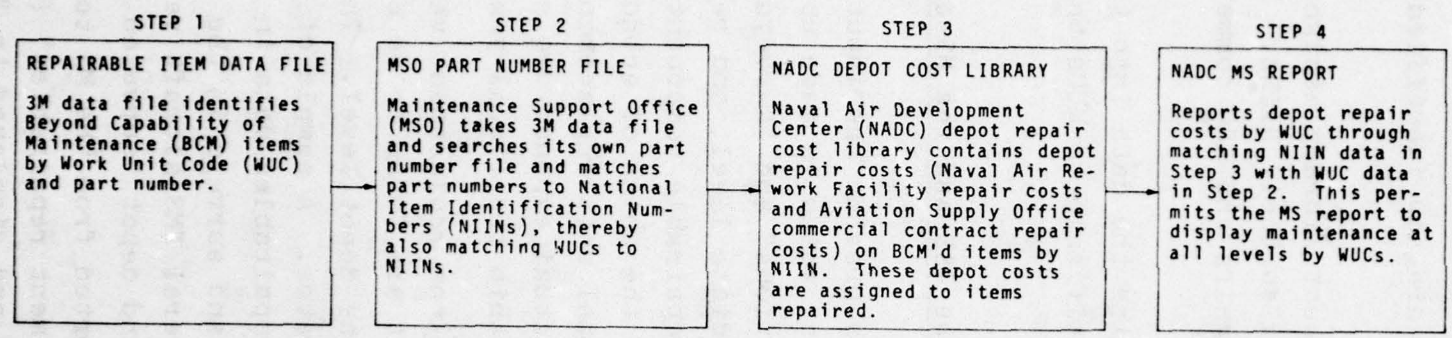

Figure 8. LINKAGE BETWEEN 3M ORGANIZATION AND INTERMEDIATE MAINTENANCE ACTION DATA AND DEPOT REPAIR ACTIONS THROUGH NARFs AND ASO COMMERCIAL CONTRACT WORK IN THE NAVY VAMOSC-AIR MAINTENANCE SUBSYSTEM (MS) REPORT

Number (NIIN). Since each part-numbered item in the RIDF has a WUC identification, the items are now identified by part number, NIIN, and WUC.

In Step 3, the NADC depot cost library assigns repair costs to the BCM items according to their NIINs. It is according to NIINs that NARF repairs and ASO commercial contract repairs are recorded.

The final step is to organize the data into the NADC MS report. The depot cost is identifiable to WUCs through the WUC-Part-Number-NIIN linkage.

f. Relationship Between the TSS and the MS and MSD Systems

The NADC MS and MSD reports provide one input category to the TSS, replacement repairables, which is made up of two categories in the MS report, "attritions" and "surveyed repairables." Attritions occur at the intermediate level, and record the replacement value of normally repairable components of a given TMS that are found to be beyond the point of economical repair. Attritions are based on the actual unit replacement cost and fiscal year attrition, not on actual expenditure since all items are not necessarily replaced within the fiscal year.

Survey repairables records the replacement value of normally repairable components that are found to be beyond the point of economical repair at the depot level. This cost is based on actual repair/survey rates. A sample of the data verifies that the replacement repairables data in the TSS are consistent with the attritions and surveys in the MS and MSD reports. A random check of several TMS aicraft verifies that intermediate "attritions" (A) and depot "surveyed repairables" (S) are added together and reported from the MS to the TSS, and recorded in the TSS as "replacement repairables" (RR). Data are taken from the 1976 reports and displayed in Table 20.

Table 20. A COMPARISON OF THE COST OF REPLACEMENT REPAIRABLES IN THE TSS WITH ATTRITIONS AND SURVEYED REPAIRABLES IN THE MS BASED ON FY 75 DATA FROM 1976 VAMOSC-AIR FOR 9 TMS

		Taken from MS		
TMS	RR From TSS*	A*	S*	A+S*
F-4B	$ 636	$ 249	$ 388	$ 637
RF-4B	185	84	102	186
F-4J	2780	1084	1697	2781
F-4N	2686	2078	609	2687
RF-8G	203	77	127	204
F-8H	187	12	176	188
F-8J	522	141	382	523
F-8K	243	157	87	244
F-14A	686	278	409	687

*Data in thousands of dollars.

It seems clear that the Navy VAMOSC maintenance subsystem provides potential data coverage at the WUC level to permit cost analyses techniques at detailed avionics equipment levels to be pursued.

5. Summary

This section reviewed the Navy support cost estimating methodologies that are currently utilized for component estimates. The F-18 internal NAVAIR tracking model takes total weapon system replenishment spares (regression estimates) and allocated them to 2-digit WUCs based on F-4 experience. Although this is currently used only to estimate a component level baseline after DSARC II for each 2-digit WUC, it could be used as an initial cost estimate.

Other Navy models could be employed at the component level early in a program's acquisition cycle by the use of analogy data, as suggested earlier for several Air Force models.

The Navy data systems are organized through the NALCOMIS VAMOSC data management systems to provide detailed 2- and 7-digit WUC support cost data. The VAMOSC Maintenance Subsystem has successfully linked organizational and intermediate maintenance data with depot maintenance data through a WUC-NIIN interface.

D. SUMMARY

Support cost estimating methodologies, policies, and data systems are fundamentally similar in the Air Force and the Navy, but they differ in the emphasis they receive and the uses to which they are put.

Both Services have accounting component support cost models, but the Air Force Logistics Command Logistic Support Cost (LSC) model is more extensively developed and applied than the Navy Material Command Equipment Life Cycle Cost model. Both Services have parametric regression support cost models, but the equations developed through the Naval Air Systems Command are more extensively developed and applied than the regression equations in the Air Force CACE model. The CACE model relies primarily on historical factors.

The data systems available to both Services report costs for maintenance at all levels and spares and repair parts support, as well as other support costs. However, the integration of the data outputs of these systems into consistent, unified support cost data bases for each Service is currently at a different stage of development in each Service. The Air Force OSCER system is currently reporting support cost data at the weapon system level but not at the component level. The Navy NALCOMIS Maintenance Subsystem has produced two-digit WUC component support cost data for Fiscal Years 1975 and 1976, and the 1977 report is in process.

Chapter III

CONTRACTOR COST ESTIMATING METHODOLOGIES FOR FIGHTER AIRCRAFT AVIONICS

A. INTRODUCTION

Commercial defense contractors are interested in avionics support cost estimating methodologies because support costs are explicitly identified in DoD acquisition policy documents as major decision items,[1] and because avionics equipments account for large shares of the support costs generated by fighter aircraft.[2] Statements made by contractors, OSD officials, and Air Force and Navy personnel all confirm the high interest priorities that each of these groups places on avionics cost estimates for proposed aircraft weapon systems, estimates which can provide

[1]DoDD 5000.1, January 18, 1977, *Major System Acquisitions;* DoDD 5000.2, January 18, 1977, *Major System Acquisition Process;* DoDD 5000.28, May 23, 1975, *Design to Cost;* DoDD 4105.62, January 6, 1976, (amended March 3, 1977), *Selection of Contractual Sources for Major Defense Systems.* DoDD 4105.62 specifically requires that the source selection plan prepared by the involved Service will include guidelines for making trade-offs among and between performance characteristics of the proposed systems and their development, production, and operating and support costs, as well as the delivery schedule and quantity of the proposed systems and any applicable qualitative requirements. This early specification of guidelines for trade-offs between performance characteristics and costs, including O&S costs, requires the contractors to explicitly explore the quantitative functional relationships between performance characteristics and O&S costs, and these explorations are embodied in alternative methodological approaches to avionics support cost estimates.

[2]Avionics component maintenance costs for fiscal year 1975 for 13 attack and 7 fighter TMS aircraft in the Navy averaged 41 percent of total component maintenance costs. The low was 25 percent for the F-8K, and the high was 62 percent for the A-6B. Avionics as defined here includes equipment in WUCs 51 through 76 inclusive. Data are from the *NALCOMIS-O&S (VAMOSC-AIR) Maintenance Subsystem Report,* December 31, 1976.

objective bases for programs to promote avionics cost control and effectiveness.[1]

The entire range of support cost estimating methodologies is available to avionics equipment and prime aircraft weapon system contractors, including the six major methodological approaches listed below and discussed later:

(1) Engineering bottoms-up
(2) Analogy with existing systems
(3) Accounting add-up
(4) Simulation
(5) Parametric regression
(6) Subjective expert judgment.

Although all of these methodological approaches are used by contractors to estimate support costs, IDA discussions with several of the contractors indicate that early conceptual stage (pre-DSARC I milestone decision) support cost estimates are most frequently made through the application of engineering and analogy approaches; the validation and demonstration stage (post-DSARC I, pre-DSARC II) estimates are usually accomplished through engineering and analogy approaches with some utilization of accounting and parametric approaches; and the full scale development stage (post-DSARC II, pre-DSARC III) estimates may employ all six of the approaches mentioned above, but with increasing reliance on bottoms-up and accounting approaches that use real world test data on prototype systems as the data become available.

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[1]J.F. Digby, *DoD Actions to Control Avionics Life-Cycle Costs*, RAND Working Note 8234-ARPA, The RAND Corporation, Santa Monica, CA, May 1973; D.J. Dreyfus, *A Survey of Costing Methods in the Avionics Inudstry*, RAND Working Note 8235-ARPA, May 1973; C. David Weimer, *The Application of Design-to-Cost Acquisition Policies to Selected Electronic Subsystem Development Programs*, IDA S-459, Institute for Defense Analyses, Arlington, VA, June 1975; E.N. Dodson et al., *Cost Analysis of Avionics Equipment*, Report 73-441, General Research Corporation, McLean, VA, February 1974; Major Richard W. Grimm, *Fire Control Radar and Airborne Computer Cost Prediction Based on Technical Parameters*, Wright-Patterson AFB, Ohio, Air Force Avionics Laboratory, September 1973.

Major perspectives assessed in the discussions to follow include the following:

(1) Two categories of contractors should be distinguished, avionics equipment-producing firms like Hughes, Rockwell-Autonetics, and Westinghouse; and avionics equipment-using firms like Grumman, McDonnell Douglas, General Dynamics, and Northrop.

(2) Various contractor cost estimating processes interact throughout the conceptual and validation stages leading to source selection and the DSARC II milestone, and as a result the engineering expertise of equipment-producing contractors can be included in the accounting build-up approaches of prime contractors;

(3) Contractors are capable of providing detailed avionics equipment support cost estimates earlier in the acquisition process than they are formally required to provide by DOD policies and regulations;

(4) Several cost estimating model building efforts are underway to broaden the generality and applicability of support cost estimating techniques;

(5) Contractor support cost data bases rely heavily on the data provided through the Air Force and Navy data systems discussed in Chapter II. Each firm usually receives data related only to its own systems and equipments; however, a firm can receive data on other firms' systems and equipments if it is awarded study contracts that require such other-firm data. The Grumman Aerospace Coporation contract with the Air Force Flight Dynamics Laboratory,[1] and the Westinghouse Electric Corporation contract with the

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[1]The Grumman contract is being pursued with the Lockheed-Georgia Company, *Modular Life Cycle Cost Model for Advanced Aircraft Systems*, Contract No. F33615-76-C-3056. As an example of data acquisition, Grumman-Lockheed received logistics and design data for the following aircraft: A-3D, A-4D, A-5A, A-6E, EA-6B, F-4B, F-8U, F-14A, F-110A, F-102A, F-104C, F-106B, C-133A, KC-135A, C-130A, C-2A, C-5A, B-47B, B-52D, B-58, RB-66B, E-2A, T-38, T-39 (third oral briefing to Air Force, June 22, 1977).

Air Force Avionics Laboratory,[1] are examples of contractor access through study contracts to Service data on the avionics equipments of other firms.

(6) Airframe contractors have well-developed avionics engineering capabilities which permit them to prepare avionics equipment bench versions of proposed avionics equipment on new F-X aircraft. These capabilities enable the airframe contractors to specify quite precisely the avionics equipments they wish avionics equipment producers to bid on. The important ingredients that the airframe contractors lack is production experience in large quantitites for avionics equipments, and reliability and maintainability parameter estimation in the conceptual stages of avionics equipments.

Cost estimating methodologies are varied and well-developed, but their full potentials for providing avionics equipment support costs to the Services and OSD before DSARC II are not fully exercised in the form of avionics support cost estimates required by and presented to OSD and the Services.

B. THE CONTRACTOR COST ESTIMATING PROCESS

Two major categories of contractors are identified as participants in the avionics support cost estimating process depicted in Table 21. The avionics equipment-producing firms like Hughes and Westinghouse actually manufacture avionics equipments while the avionics equipment-using firms like McDonnell Douglas and Grumman are prime weapon system contractors that purchase (through sub-contracting) avionics equipment from the producing firms.[2] Both of these categories of contractors are called upon, by each other and by DoD, to estimate avionics support costs during the acquisition process.

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[1] *Predictive Operations and Maintenance Cost Model*, Statement of Work Purchase request number FY11757720318, Westinghouse Electric Corporation, 1977.

[2] This distinction is similar to that made in D.J. Dreyfuss, *A Survey of Costing Methods in the Avionics Inudstry*, RAND Working Note WN-8235-ARPA, Santa Monica, CA, The RAND Corporation, May 1973 (continued on page 136)

Table 21. COMMON SEQUENCE OF CONTRACTOR AVIONICS SUPPORT COST ESTIMATING PROCEDURES DURING CONCEPTUAL AND VALIDATION STAGES

Step	Type Firm	Cost Estimating Activity
1	Aircraft Prime Contractor	Uses analogy or parametric regressions to estimate avionics support costs as a single lump, not broken out by pieces of equipment.
2	Aircraft Prime Contractor	Requests acquisition and support cost estimates and support parameters such as MTBF for types of equipment from avionics producers.
3	Avionics Equipment Producer	Engineering bottoms-up or analogy estimates of acquisition and support costs and support parameters such as MTBF for specific equipments, reported to prime contractor.
4	Aircraft Prime Contractor	Uses accounting build-up or parametric estimates with avionics equipment producers estimates and support parameters as inputs.
5	Avionics Equipment Producer	Uses aircraft prime contractor total aircraft weapon system estimates as inputs to modify analogy and engineering estimates, reports up-dated estimates to aircraft prime contractor.
6	Both Avionics Equipment Producer and Aircraft Prime Contractor	Continue to iterate cost models by inputting each other's up-dated data and reporting iterations to each other. In this process, all cost estimating methodologies may interact through iterative processes.

As shown in Table 21, the equipment-producing contractors rely heavily on engineering and analogy approaches early in the acquisition process, while the equipment-using prime contractors rely heavily on accounting and parametric approaches in addition to analogy. The sequence of avionics support cost estimating procedures shown in Table 21 displays the interactive nature of contractor cost estimating. With the full range of cost estimating methodologies available, the prime contractor in step one of the table relies on analogy to existing systems or parametric regression equations to estimate avionics support costs early in the conceptual phase between DSARC 0 and DSARC I. At this point, the potential prime contractor is only interested in gross aggregate cost estimates for avionics equipment as a single total. Although the prime contractor may have sufficient engineering expertise to do a bottoms-up estimate for avionics at the level of each piece of avionics equipment, it is most likely that a factor will be applied to the acquisition cost estimate for the proposed weapon system to derive a rough rule-of-thumb aggregate estimate for total life cycle support costs. This aggregate factored estimate may be broken down to separate factored estimates for avionics, airframe, and propulsion, as shown in alternative one in Figure 9. This initial support cost estimate is purely a function of historical experience with prior weapon systems produced by the contractor and the new

(contd)...Dreyfuss surveyed 10 firms called "contractors," and divided them into three categories: avionics producers; avionics users/developers; and research firms. Our survey of support cost methodology does not include the research firms category. The distinction between avionics equipment producers and aircraft prime contractor avionic equipment purchasers or users is also consistent with the usage of similar distinctions in H.P. Gates *et al.*, *Electronics-X: A Study of Military Electronics with Particular Reference to Cost and Reliability*, IDA Report R-1975, Arlington, VA, Institute for Defense Analyses, January 1974, and C.D. Weimer, *The Application of Design-to-Cost Acquisition Policies to Selected Electronics Subsystem Development Programs*, IDA Study S-459, Arlington, VA, Institute for Defense Analyses, June 1975.

ALTERNATIVE 1, HISTORICAL ANALOGY FACTORS

$$C_1 = C_{11} + C_{12} + C_{13}$$

Where C_1 = Total weapon system support costs

$$C_{11} = Z_{11} X_{11}$$

$$C_{12} = Z_{12} X_{12}$$

$$C_{13} = Z_{13} X_{13}$$

C_{11} = Avionics support cost

C_{12} = Airframe support cost

C_{13} = Propulsion support cost

Z_{11}, Z_{12}, Z_{13} = Factors developed from historical experience on analogous weapon systems

X_{11} = Avionics acquisition cost or total weapon system acquisition cost

X_{12} = Airframe acquisition cost or total weapon system acquisition cost

X_{13} = Propulsion acquisition cost or total weapon system acquisition cost

ALTERNATIVE 2, PARAMETRIC REGRESSION

$$C_1 = \alpha + \beta_1 X_1 + \beta_2 X_2$$

Where C_1 = Avionics support cost

α = Constant term representing avionics support cost that is independent of weapon system, i.e., storage and disposal costs

β's = Regression coefficients which quantify the relationships between the cost (C_1) and the independent variables

X's = Independent variables such as total weapon system acquisition cost or avionics acquisition cost

Figure 9. PRIME CONTRACTOR AVIONICS SUPPORT COST ESTIMATES DURING CONCEPTUAL STAGE

proposed weapon system's acquisition cost estimate, which itself may be a factored result of historical experience with analogous systems or a parametric regression output. Thus, the step one avionics support cost estimating process in Table 21 frequently follows the procedure outlined in Figure 9 for alternative one.

A variation of the historical analogy factor technique is to replace the Z factors with Z-prime (Z') factors that represent historical factors modified by subjective expert judgments about the differences between analogous systems and the new proposed system. The Z' judgment-modified factors are not shown in Figure 9, but would simply replace the Z factors in the equations.

Alternative two in Figure 9 is a parametric regression approach, which amounts to a formal statistically quantified version of the analogy factor approach. Here, historical data for existing avionics systems' support costs (C_1) are processed through regression techniques with data for the existing systems' acquisition costs (either total weapon systems acquisition costs or avionics system acquisition costs). The result is a set of beta coefficients (β's) that generate the new proposed system's avionics support costs when values for the new system's acquition costs are entered in the equation. The β-coefficients are like the Z-factors in the analogy technique, but with the added feature of statistical properties that can be measured to ascertain the certainty with which we should accept the β's as representative of the real relationship between avionics support costs and acquisition costs.

Thus, avionics support cost estimates during the conceptual phase are functionally related to acquisition cost estimates, both in the analogy approach and in the regression aprroach used by prime weapon systems contractors. If support costs are

reported for the DSARC I milestone decision,[1] they are reported at an aggregate level for the entire weapon system, or for the aggregate avionics, airframe, and propulsion breakdown of the total system. If they are not reported, they are still useful for internal firm assessments of the magnitude of support costs for the proposed program.

Step two in Table 21 shows the weapon system prime contractor requesting acquisition and support cost estimates and logistic characteristics like MTBF from avionics equipment producers. In step three, the equipment-producers utilize their engineering expertise to perform bottoms-up or analogy estimates of acquisition and support costs and support parameters. These estimates are reported to the prime contractor, and in turn they are incorporated into the prime contractor's analogy model or regression equations. In this manner, the engineering expertise of the avionics equipment producers becomes the source of independent variables in the analogy and regression equations exercised by the prime contractors. These equipment-producer engineering estimates may be incorporated into formal prime contractor presentations for the DSARC I decision, and the prime contractor begins to use accounting build-up models to estimate avionics equipment support costs, as shown in step four in Table 21. These accounting models may still be heavily dependent on engineering bottoms-up estimates from the equipment-producers. In step five of Table 21, the avionics equipment producers use the prime contractor acquisition and support cost estimates to modify their engineering or analogy estimates and these modified estimates are then reported to the prime contractor where they are incorporated into the prime contractor's estimates. This process continues throughout the validation stage and up to and

[1]The DSARC-I decision is approval to proceed with the validation phase, culminating in a Service source selection decision, which is in turn quickly followed by a DSARC-II milestone decision approving or denying the full scale development phase.

including the equipment-level support cost estimates reported to the Service selection authority for the source selection decision.

Once beyond DSARC II, the contractors and the Services acquire prototype equipments which are tested for support characteristics. The test data are then entered into accounting and engineering equations to provide more realistic cost estimates.

The most important message of Table 21 is that the contractor cost estimating process for avionics support costs is not a single process but is instead made up of several different processes represented by different cost estimating methodologies which interact. These interactive iterative processes are the dominant characteristics of contractor avionics support cost estimating. The implication to be extracted from Table 21 is that although engineering bottoms-up approaches are most frequently utilized directly by the avionics equipment producers, the aircraft prime contractors enjoy the fruits of these exercises when the engineering approach estimates are included as inputs into the accounting or parametric approaches most frequently used by the prime contractors. Similarly, the accounting build-up or parametric approaches used by the prime contractors react back on the avionics equipment producers and further refine their data inputs. Contractor avionics support cost estimates are not produced in a vacuum where the engineering expertise of the equipment producers is denied to the prime contractors, nor where the total weapon system perspective and integration expertise of the prime contractors is denied to the equipment producers. Thus, the contractors practice to a significant degree what the military Services currently lack, an integrated methodological approach to avionics support cost estimating.

Contractor support cost estimating has been encouraged by government policies to consider support costs explicitly in

acquisition decisions. Interpreted in terms of these policies, it is possible to simply state that the contractors are willing to do whatever the government requires in order to participate successfully in the acquisition process. Most of the contractors IDA interviewed indicated that they used the AFLC LSC accounting model or the NAVMAT LCC accounting model to report avionics equipment level support costs to the Services. But reporting costs to the Services is not necessarily synonymous with contractor avionics support cost estimating methodology. In fact, the utilization of Service-developed accounting models like AFLC LSC and NAVMAT LCC are made in addition to and frequently simultaneous with or after the exercising of the processes detailed in Table 21. To a degree, the Service accounting models enter the iterative processes and become part of the whole. But it is also true that the analogy, engineering, parametric, and other approaches are frequently exercised independent of the Service accounting models. Thus, contractor support cost-estimating methodology exists independent of the Service models, although by the nature of the source selection process that specifies models for contractor use, the contractor methodology and the Service methodology interact and join as phases in the overall contractor estimating process.

A proper understanding of the sequential flow of estimating procedures in Table 21 relates to the issue of what the contractors are capable of providing versus what they have chosen to provide in response to DoD policies and requirements. The contractors IDA spoke with all agreed that they are capable of providing avionics equipment support cost estimates at the two-digit WUC level (or even lower) early in the coneptual stage before DSARC I. Such estimates would be based on analogy to similar existing systems with engineering expert judgments adjusting key logistic parameters to represent desired, expected, or required performance characteristics of the proposed new systems.

The interviewed contractors repeatedly expressed two misgivings about such early equipment-level O&S estimates. First, they doubted the utility of these early estimates for either the military Services or OSD. Their doubts were not grounded in a refusal to accept the potentials for making comparisons among alternative system designs during the conceptual stage of the acquisition process; they were all fully aware that more detailed information provided early in the process could permit the Services and OSD to focus on narrower issues of design and performance characteristics versus costs. They all also agreed with the conventional wisdom that more than half of total life cycle support costs are determined by decisions made prior to the DSARC II milestone, so their skepticism about the usefulness of early equipment support cost estimates that could permit performance and design versus cost trade-offs was even more surprising. Granting all of these potentials of early equipment support cost estimates, the contractors simply do not appear to believe that OSD is serious about making acquisition decisions based on life cycle costs including support costs. In their views, a contractor proposal offered for source selection that carries high acquisition costs but low life cycle costs relative to another proposal is doomed to rejection by the Service's source selection authority. Seen in this light, contractor capabilities to provide early estimates of support costs at the avionics equipment level are unimportant to the competitive success of the companies.

A second contractor misgiving about early conceptual stage equipment support cost estimates is that these will become hard numbers that the contractors will be expected to adhere to by the Services and OSD. The contractors resist being tied to numbers developed early in the acquisition process.

Before investigating specific examples of contractor cost estimating methods, we examine next the policies that provide

the impetus for avionics support cost estimating and define the interfaces between contractor estimating methods and the Service methods.

C. POLICIES AND PROCEDURES

The DoD policies and procedures that influence contractor support cost estimates are those that define the major weapon system acquisition process. The applicable directives that define these policies and processes were discussed earlier in Chapter I.

The "general policy" section of DoDD 4105.62 was amended in March 1977 to require special emphasis on the promotion of competition in the selection of contractual sources for major defense acquisitions.[1] To this end, the directive requires that the pro forma nurturing of competition should be supplemented by "...certain additional factors which more appropriately must be considered when the selection of a source is to be made from among alternative system design concepts." One additional factor is the broadening of the commercial base from which proposals are to be initially solicited, and a second additional factor explicitly identifies trade-offs between system performance characteristics and mission need, schedule, capability objectives, and operating constraints. The language of this directive makes it clear that the relationships between performance characteristics and support costs are to be explicitly considered and incorporated into source selection documentation and decisions.

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[1]Change 1, March 3, 1976, Section III.A.2,; "The selection of contractual sources may be either as a result of a competition among alternative system design concepts or as a result of a more restrictive competition where the system has previously been defined...the solicitation should be so structured so as to reflect the mission need, schedule, cost, capability objectives, and operating constraints but not technical approach or main design features."

The directive also includes new language which indiciates that main design features are not to be identified by the government in the solicitation documents but these features should be identified in the contractor proposals. This explicitly recognizes considerable flexibility in the specific design features that are promoted by each contractor, and includes flexibility in support cost techniques which relate to a particular design. But this flexibility in support cost techniques is reduced by the likelihood that the Service will specify a particular equipment-level support cost model to be used for the contractor's source selection submissions.

The source selection process as part of the larger weapon system acquisition process has been carefully detailed in other surveys and reviews, and the latest military Service interpretations of specific relationships can be found in documents like the AFSC/AFLC Life Cycle Cost Procurement Guide.[1] Even in light of directives, guides, and other official documentation, IDA discussions with avionics equipment-producing and equipment-using contractors suggest that considerable additional discipline needs to be introduced into the cost estimating processes followed by DoD and the private contractors. The contractors suggest that additional requirements and specifications of weapon system performance characteristics and logistic characteristics early in the conceptual stage could improve contractor cost estimates. These ideas are echoed in a report prepared by the National Security Industrial Association, a group composed of contractor life cycle and support cost experts.[2]

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[1]J.E. Kernan, Jr., and L.J. Menker, *Life Cycle Cost Procurement Guide*, Wright-Patterson AFB, Ohio, Joint AFSC/AFLC Commander's Working Group on Life-Cycle Cost, July 1976. This guide contains a major section devoted to the source selection process and is directed at the validation and full scale development phases of the acquisition process.

[2]D. Earles and H.I. Starr, *Life Cycle Cost, Findings, and Recommendations*, Logistics Management Advisory Committee of the National Security Industrial Association, April 1976. "The Committee (continued on page 145)

Generally, the lack-of-discipline complaint is grounded in the argument that the contractors are not given sufficient information about new proposed systems early enough in the acquisition process. The NSIA recommendation is for DoD to provide increased detail concerning cost goals and requirements early in the conceptual stage.

Another NSIA recommendation made to DoD is that life cycle cost estimates, including support costs, be estimated and reported in a continuous process throughout the acquisition cycle and not just at one or two key points in the cycle.

A third recommendation is that support cost estimates be made at the replaceable equipment level since estimates are already being made internally by contractors at this level in order to acquire visibility into support concept differences early in the conceptual stage of the acquisition process.

The IDA summary view of contractor policies concerning support cost estimating methodologies is that whatever level of detail the government requests will be provided, but that in the contractors' views, the government does not ask for

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(cont'd)...objective to have the life cycle cost of a system managed throughout its development, production, and operational use. This requires that it (LCC) be specified, designed to, monitored, tested and evaluated. Except in a few recent cases, this is not happening. On many programs, life cycle cost estimates are one-shot affairs and are not programmed as scheduled activities. Accordingly, LCC activities are not generally integrated into overall development plans." The committee recommends that: (1) LCC goals and requirements be specifically stated in requests for proposals and statements of work; (2) LCC estimates should be documented as part of program plans and if applicable as separate contractor data requirement lists; (3) the requirements for performance, reliability, maintainability, availability and cost be correlated such that they are compatible; (4) LCC estimates be required with systematic updating and reporting; (5) DoD simplify the methods required for making LCC estimates and emphasize tailoring the depth of estimates to the decisions to be made; (6) LCC, reliability analysis, maintainability analysis and logistic support analysis shall be done such that they are correlatable to the line replaceable unit (black boxes) of equipment.

enough information from what is already available at the contractor level. Even if the government did ask for support cost detail early in the acquisition process, there is no officially approved standardized format within which to report the information. Standardized models with standardized equations and requirements are necessary if DoD is to be able to take advantage of the full range of support cost estimating activity that goes on at the contractor level before DSARC II.

With these policies as foundations, we can move to a discussion of cost estimating methods in the next section.

D. COST ESTIMATING METHODS

As mentioned earlier, the six major cost estimating methodological approaches available to contractors are:

(1) Engineering bottoms-up
(2) Analogy with existing systems
(3) Accounting add-up
(4) Simulation
(5) Parametric regression
(6) Subjective expert judgment.

Each of these approaches is discussed in turn in this section, and examples of how they are applied by typical contractors are presented where appropriate.

In general, contractor support cost estimating for avionics and other equipments is well developed and capable of adaptation to many modeling techniques.

1. Engineering Bottoms-Up Approach

Each avionics equipment producer is capable of exercising its accumulated engineering expertise to develop bottoms-up acquisition cost estimates early in the acquisition cycle, certainly before DSARC II and DSARC I. The engineering approach

amounts to building a proposed system on paper and costing each piece, part, and unit of equipment that makes up the entire avionics equipment. The process involves a detailed preliminary design which counts items like the number of drawings, tests, piece parts, and system-subsystem interfaces. Given an aquisition cost determined by engineering expertise at the bottoms-up levels, the transition to support costs for the equipment must be made. Given that a detailed design has been produced, nearly any methodological technique is open to contractors. Relating physical design and performance characteristics to support costs is the goal, and the means to the goal may be dictated by the specific requirements imposed on the contractor by the Service in the acquisition solicitation documentation.[1] Thus, the major output of the engineering bottoms-up approach is acquisition cost, which can then be used in various modeling approaches to relate the preliminary design to support costs. This implicitly assumes the support costs are explicit functions of acquisition costs, and this appears and reappears frequently in the literature and research approaches to support cost estimating.

The major virtue of the engineering approach is that acquisition costs are provided at the LRA level or lower. This sub-component level of acquisition cost detail permits the utilization of various models which translate acquisition costs for sub-components into support costs through an appropriate functional relationship.

A typical example of the engineering bottoms-up approach is provided by the Westinghouse Electric Corporation's cost estimates for the Electronically Agile Radar (EAR) system.[2]

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[1]Items like the official Statement of Work (SOW), Request for Proposal (RFP), Request for Quote (RFQ) are all documents that can specify the detail and kinds of costs required to be reported for the source selection process.

[2]*Electronically Agile Radar System/Cost Effectiveness Plan,* Westinghouse Electric Corporation, 10 December 1976, LSC model inputs required from the contractor.

Engineering expertise was used to develop acquisition cost estimates for the various equipments in the EAR system, and then these estimates were input into a modified version of the AFLC LSC accounting support cost model.

The cost analysis group at Westinghouse Electric was given responsibility for both the acquisition and support cost estimates. Two reasons were offered. First, the cost group would require the acquisition cost estimates as independent variable inputs into the LSC model in order to produce support cost estimates, so it was decided that they should shepherd the effort from its inception even though acquisition costs in the conceptual stage are purely engineering estimates in equipment producing firms like Westinghouse. Second, the cost group could coordinate, across various management boundaries, the efforts of both engineers and policy decision-makers.

The objectives of the Acquisition Cost Modeling (ACM) phase of the EAR program were to:

(1) provide visibility of cost estimates of a design against cost targets suitable for trade-offs,

(2) provide estimates of costs as inputs to the Westinghouse version of the LSC model.

Cost quotations are derived within the Westinghouse cost accounting system. In establishing EAR cost estimates, the components of cost estimates are generated in terms of Westinghouse codes and nomenclature. The codes for these estimates are given in Table 22. Westinghouse procedures divide costs into two categories for acquisition estimating, inventory cost of sales (ICS), and customer order development (COD). Generally, ICS is the effort that adds value directly to a physical piece of equipment (i.e., material, manufacturing labor, manufacturing

[1]See Chapter II, Figures 5 and 6 for a comprehensive identification of the LSC model inputs required from the contractor.

Table 22. WESTINGHOUSE ACCOUNTING CODE

Type Code	Nomenclature
A	Engineering shop follow
E	Engineering changes to the product
F	Engineering changes to test equipment
H	Manufacturing labor
J	Manufacturing Material
K	Tooling
L	Shop development
N	Manufacturing test
P, Q, R	Factory test equipment
S, T	Quality assurance
V	Manufacturing inspection

test, and manufacturing inspection). COD is all other indirect costs necessary for the manufacture of the product.

A view of the engineering approach as it is implemented at Westinghouse is offered through examination of how manufacturing labor costs were estimated for EAR.

As many as forty cost centers in Westinghouse contribute to estimating manufacturing labor costs. These centers are grouped into categories of feeders and assembly. Feeders are manufactured items that become components in assemblies such as chassis, inductive equipment, and base printed circuit boards. Assembly, as it sounds, refers to the actual assembly of components into a final product.

Major operations performed within feeder and assembly centers are categorized into set-up and run time operations.

Set-up time is work done to prepare the work stations for performing a required manufacturing operation. Run time is the actual work performance of the manufacturing process. Set-up and run times in hours are established for either the performance of each operation, or as an aggregate of a number of operations on a center basis as appropriate. In such an analysis, established hours are called standard hours and represent unit average time to perform the operation for the 1000th unit. A shop routing is a work flow estimation that identifies operations and standard hours, and it represents the content of work to be performed. Learning curves are then applied to run time standard hours to derive the hours per system for the quantity being considered. Learning does not apply to set-up time; this is a function of the time over which the units are to be produced or is a function of the number of units produced.

Each minor cost center also operates with an efficiency factor the reciprocal of which is defined as a conversion factor. This factor is used to convert standard time to elapsed time in those centers which charge elapsed time. For the EAR program Westinghouse defined the factor as 1.0.

Summarizing the foregoing narrative in a manufacturing labor cost engineering bottoms-up equation, it reads:

$$HC_{70} = [(F1)(K1)+(F2)(K2)+(A1)(K1)+(A2)(K3)](K4)(K5)(K6)(K7)$$

where:

HC_{70} = manufacturing labor cost in 1970 dollars
F1 = feeders standard hours for set-up time
F2 = feeders standard hours for run time
A1 = assembly standard hours for set-up time
A2 = assembly standard hours for run time
K1 = production rate factor
K2 = feeders run time learning curve factor
K3 = assembly run time learning curve factor

$K4$ = an allowance for changes to the product

$K5$ = normal production allowance (NPA) factor

$K6$ = a costing rate adjustment factor based on NAVPRO negotiation

$K7$ = costing rate in dollar per hour.

This lengthy equation exemplifies the engineering expertise that goes into making up avionics equipment-producer-firm acquisition cost estimates. Manufacturing labor cost discussed here is only one of the cost estimates listed in Table 22, the sum total of which make up the EAR acquisition cost estimates for each piece of EAR equipment. Similar cost engineering bottoms-up equations are developed and used to compute the other cost estimates.

2. Analogy to Existing System

In a sense, the engineering bottoms-up approach is very much like drawing an analogy to an existing system, because the design engineer calls upon accumulated experience with prior systems to develop the piece part count and other physical characteristics for a new preliminary design. In addition, reliability and maintainability engineers utilize their cumulative experience with prior systems to develop estimates for characteristics like mean time between failure and mean time to repair. New systems are not designed out of thin air without a baseline to work against, and existing systems and accumulated experience on those systems provide the baseline. This is, in effect, costing by analogy, but perhaps not quite as rigidly as is usually meant by this terminology.

Usually, analogy costing does not mean the engineering approach, but instead means taking an existing system that is closest to the new proposed system and using its cost characteristics and profiles as baselines against which delta changes will be entered to define the new system. A complex version

of this approach entails taking subsystems and components from many different aircraft, each component the closest to the new proposed design, and building the analogy to the new aircraft just as the new aircraft is itself built on paper. This complex analogy approach at the component level has the benefit of more nearly fitting the analogy components to the new proposal, but it has the disadvantage of losing the effect of interactions between and among components. These interactions may be quite important to the engineer's assessment of a support characteristic like MTBF. For example, if the engineer is examining an existing operational radar as the best analogy to a proposed new radar, the reported MTBF of the existing radar must be adjusted up or down or held constant to reflect the expected MTBF of the new radar. To make the adjustment, the engineer must know the real MTBF drivers for both the existing and the proposed radar. If any of the MTBF dirvers for the existing radar are related to the airframe upon which the radar flies, or are related to other components interfaced with the radar, then these must be reflected in the engineer's judgment of how to adjust MTBF. While this is coneptually obvious, it is by no means obvious that the MTBF data can be used as the baseline from which to make the adjustments. The MTBF data that the engineer sees on the existing radar may strongly reflect, for example, the place in the aircraft that the radar is located. If so, how does the engineer adjust the observed MTBF to account for this physical design characteristic that drives reliability? According to the contractor engineers with whom we talked, there are no hard and fast rules for this kind of problem. The solution depends heavily upon the experienced judgment of the engineer.

The fundamental issue characterized by this radar MTBF example is that the engineers must know the real cost drivers behind MTBF, MTTR, and other support characteristics that in turn drive support costs. The analogy techniqe may be viewed,

we believe, as getting at the heart of the avionics support cost estimating problem. The reason is that the reliability and maintainability engineers must make expert subjective judgments, and these judgments are based, at their best, on an understanding of the real support cost drivers. But these understandings are not systematically formalized in design or reliability and maintainability handbooks that identify the relevant cost drivers and relate them to MTBF, MTTR, and other support characteristics. Instead, these drivers and their functional relationships to support characteristics reside in the cumulative experience of the design and reliability and maintainability personnel of individual contractors.

An entirely separate issue is that there may be different cumulative bodies of experiences at different contractors, so there may be important differences between the subjective judgments made at two difference avionics contractor firms concerning the application of the analogy technique to new proposed avionics equipments. In the early conceptual stages of equipment design and costing for support, these differences between firms may make Service and OSD assessments of alternative equipments offered by competing firms quite complex and difficult. (Ways for OSD to approach the independent assessment of alternative avionics equipment designs and associated support costs are discussed in Chapters IV and V.)

According to the contractors with whom IDA discussed cost estimating methodology, all are capable of engineering build-up and analogy approaches, and in the first instance of deciding to pursue a new program offered by DoD in the pre-DSARC I phase of exploratory conceptual development, certainly use these two approaches hand-in-hand to produce a broad estimate of the costs involved in a new system proposal. Some emphasized that these approaches could be implemented at any time given some information about the new system requirements. The more information available in the form of DoD requirements, the more the

AD-A054 016 INSTITUTE FOR DEFENSE ANALYSES ARLINGTON VA COST ANAL--ETC F/G 15/5
THE FEASIBILITY OF ESTIMATING AVIONICS SUPPORT COSTS EARLY IN T--ETC(U)
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engineers and other experts have to work with in building up an analogy. Regardless of which specific models the Services eventually direct contractors to use as the bases for the DSARC II and source selection approaches, the contractors agree that engineering estimates and analogies form the central character of their initial cost estimates.

3. Accounting Add-Up Approach

There are many accounting build-up models in use by various contractors, and most are based on the AFLC LSC model. This model is useful primarily as a design trade-off tool where the design is sensitive to support parameters such as MTBF. This is a critical assumption in the accounting model approach, the linkage between design parameters and support parameters. If the linkage is lacking, then the LSC-type models are somewhat insensitive to design changes.

In order to overcome problems created by multiple versions of LSC and its Navy equivalent, the NAVMAT LCC model, a combined government-contractor effort to produce a standardized accounting model, has created a new accounting life cycle cost model, CRIER, Cost Reduction is Everyone's Responsibility. The model and user's manual were prepared by contractor and Service members of the Life Cycle Task Group of the Joint Services Data Exchange for Inertial Systems.

The model uses a set of data inputs to compute RDT&E, Acquisition, and O&M costs for a piece of avionics equipment, subystem, or system. An extract from the model handbook detailing the equations and variables is presented in Appendix K of this paper. The O&M equations compute costs for three levels of maintenance as appropriate in the following categories:[1]

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[1]Each cost equation is coded with a subscript that can indicate one of three levels of maintenance. Thus, each equation can be processed for each level of maintenance if the cost category is appropriate at that level.

Direct maintenance labor
Direct maintenance material
Overhead maintenance labor
General administrative
Transportation
Replenishment spares
Replacement training
Support equipment maintenance
Maintenance management data
Inventory management.

The significant characteristics of accounting models are that they can provide substantial support cost details at low levels of indenture, and they utilize inputs, such as acquisition cost estimates, that are independently obtained through other cost estimating methodologies.

4. Simulation

There are various kinds of simulation models, including the level of repair analysis (LORA) models, and the spares optimization models like MOD-METRIC.

The LORA-type model is a technique for determining the least cost level of repair policy for new equipments as they are introduced into the Air Force industry. Most of these models fall into one of three categories: single item-single indenture; single item-multi indenture; and, systems models.

The LORA single item-single indenture model adds up the various costs of the three maintenance alternatives for a given LRU:

(1) Discard at failure
(2) Repair at base
(3) Repair at depot.

The least cost alternative is identified. This type of model requires the use of allocation procedures for the costs of items like support and test equipment used to repair more than one type of LRU. This requires several iterations of the model for each LRU to ensure that LRUs designated at a given level carry totally allocated costs.

In addition, this kind of model deos not explicitly cost out which of the three alternatives should be used at lower levels of repair such as the SRU, module, and piece-part levels. Instead, an average or a maximum cost of the three alternatives at each of these lower levels is assumed known.

The Air Force Optimum Repair Level Analysis (ORLA) model is of the kind described above, as is the Navy LORA model. Most contractors employ one of these two models when doing this kind of analysis.

The MOD-METRIC model is intended to compute the spare stock levels for base, intermediate, and depot levels for an assembly and its subassemblies. The logistics relationship between assemblies and subassemblies is identified by equations that reflect the average resupply time of an assembly as a function of the probabilities that a given assembly failure was isolated to each of the assembly components and the average resupply time for each component.

5. Parametric Regressions

IDA did not have access to specific contractor regression equations that are utilized for in-house cost estimates, either for component acquisition cost or for component support cost. All contractors agreed that they used parametric regressions based on the historical data in their data banks, but that most had too few separate weapon system component experiences to produce coefficients on the regression equations that were reliable at reasonable (1 percent or 5 percent) levels of

significance. Given access to greater data ranges, they were certain that they could develop useful regression equations that would help them translate engineering build-up acquisition costs of components at early conceptual stages to component support costs.

An example of this willingness and capability to develop parametric equations is offered by the Grumman Aerospace Corporation project to develop a "Modular Life Cycle Cost Model for Advanced Aircraft Systems" for the Air Force Flight Dynamics Laboratory.[1] This project is due to be completed early in calendar year 1978 with regression equations available for conceptual and preliminary design phase cost estimates. It is designed to produce regressions that will permit the Air Force to compare, evaluate, and determine the life cycle cost impact of competing design alternatives for transport/cargo/tanker and fighter/attack airframes, engines, and avionics. Cost data are to be extracted from Grumman's and Lockheed's in-house data banks, extensively supplemented by Air Force data on other contractors' aircraft. This is a case where an aircraft prime contractor is willing to develop avionics support cost estimating procedures even though the contractors engineering expertise does not include production line knowledge at the avionics component level. Such engineering expertise at the production level is not required here because the estimating technique is to look at historical data and to perform regressions.

Table 23 displays the parametric CERs that Grumman has tentatively identified as the major outputs of their research effort. As can be seen, there is substantial detail available at the two-digit WUC level. Currently, avionics is treated as a single lump sum inclusive of WUCs 52, 55, 56, 74, 76, and 77 (see Table 2 in Chapter I). A single equation is available

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[1]Proposal for Modular Life Cycle Cost Model for Advanced Aircraft Systems, January 5, 1976, prepared for AF Flight Dynamics Laboratory.

Table 23. COSTS FOR WHICH PARAMETRIC CERS ARE AVAILABLE THROUGH THE GRUMMAN-FLIGHT DYNAMICS LABORATORY PROJECT

Cost Element (Each cost element for which an X is entered in the table is a dependent variable estimated by a separate equation for each subsystem where the X also appears.)	Subsystems for Which CER's Are Available by Subsystem Title and Inclusive WUC's													
	Structure WUC's 11, 92	Crew System WUC's 12, 16, 49, 91, 96, 97	Landing Gear WUC's 13, 93	Flight Controls WUC 14	Engine WUC's 22 & #2 or 23	Engine Installation WUC's 24, 29	ECS WUC's 41, 47	Electrical WUC's 42, 44, 51	Fuel WUC 46	Avionics WUC's 52, 55, 56, 74, 76, 77	Weapon Delivery WUC 75	Hydraulic-Pneumatic WUC 45	Cargo Handling	Total
RDT&E														
Airframe														
Engineering														x
Manufacturing*														x
Tooling*														x
Quality Control														x
Avionics										x				
Engines					x									
PRODUCTION														
Airframe		x	x	x		x	x	x	x		x	x	x	
Wing	x													
Body	x													
Tail	x													
NACELLE	x													
Avionics										x				
Engine					x									
INITIAL SUPPORT														
Spares	x	x	x	x	x		x	x	x	x	x	x	x	
Support Equipment	x	x	x	x	x		x	x	x	x	x	x	x	
Contract Training														x
Data	x	x	x	x	x	x	x	x	x	x	x	x	x	
OPERATIONS AND SUPPORT														
Base Maintenance	x	x	x	x	x	x	x	x	x	x	x	x		
Flying Operations														x
Training														x
Depot Airframe														x
Depot Components		x	x	x		x	x	x	x	x		x	x	
Depot Engine					x									
Replenishment Spares	x	x	x	x	x	x	x	x	x	x		x	x	
POL														x
Other														x

*Separate equations are available for manhours and dollars.

for WUC 75, weapons delivery. Grumman is confident that it has sufficient data to produce avionics support cost parametric equations for each two-digit WUC, but this is not a requirement of the contract with the Flight Dynamics Laboratory.

The categories of support costs available include replenishment spares, base level maintenance, and depot component repair, among others in Table 23, but these three are directly related to the support cost focus of this paper. We believe that this Grumman work provides a viable potential for parametric two-digit WUC support cost estimating equations.

Another example of regression support cost activity in the avionics area is in the Westinghouse contract with the AF Avionics Laboratory to develop avionics equipment support cost regression equations which specifically link design parameters to support costs. This is an ambitious project that is specifically intended to produce a mathematical model which accurately predicts downstream logistic support and maintenance costs of avionics during the conceptual and preliminary design phases of the acquisition process.

An interesting feature of the Avionics Laboratory Statement of Work that was provided to potential bidders in the contract award process is the requirement that the model "...be independent of the avionics function, i.e., a generalized model that will predict support and maintenance costs for navigation equipment, radar systems, radios, etc."[1] Previous avionics support cost model research funded by the Avionics Laboratory focused on equipment-unique parametric equations, producing a separate equation for each of several types of avionics equipments, such as fire control radars and FLIRs.[2]

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[1]Air Force Avionics Laboratory, *Statement of Work: Predictive Operation-and-Maintenance Cost Model*, Purchase Request No. FY11757720318, 1977.

[2]Air Force Avionics Laboratory (AFAL) TR-73-441, *Cost Analysis of Avionics Equipment*, AFAL-TR-75-15, *Cost Estimating Relationships for Airborne Array Radars, FLIRs, and Avionics Logistic Support*, Volumes 1 and 2, February 1974.

The Avionics Laboratory suggested that Westinghouse consider the following inputs to the model, which amount to the independent variables in the regression equations (the cost drivers):

(1) Maintenance philosophy
(2) Unit acquisition cost
(3) Component type (digital, analog, hybrid)
(4) Component technology (number of functions-gates, tube, solid state, integrated circuits)
(5) Component density
(6) Component count
(7) Power dissipation
(8) Total volume
(9) Total weight
(10) Quantity of systems
(11) Type of aircraft
(12) Schedules (engineering, production)
(13) Years of operations
(14) Technology (BITE-yes or no, etc.)
(15) Utilization factor
(16) Technological improvement factor
(17) Number of systems per base
(18) Packaging variables.

The desired model outputs include:

(1) Mean time between maintenance actions
(2) Mean time to repair
(3) Maintenance man hours per operating hour
(4) Predicted resource requirements for maintenance manpower, test equipment, other
(5) Initial support cost
(6) Annual support cost
(7) Relative predicted operating and maintenance costs
(8) Spares
(9) Base costs, including training

(10) Depot costs, including training
(11) Support equipment costs
(12) Documentation costs
(13) Facilities costs.

There seems to be no reluctance on the part of contractors to develop regression equations, and in early design stages they may be quite useful for relating acquisition costs to support costs and design parameters to support costs.

A widely used proprietary regression model is the RCA PRICE model. Its equations are not public knowledge, but its methodology appears to involve the use of a vast data bank of historical information at the piece-part level of detail to generate 1400 parametric equations.

The PRICE (Programmed Review of Information for Costing and Evaluation) is an RCA-developed parametric cost-modeling technique. It provides estimates of system acquisition costs based on physical parameters such as quantity, size, weight, power consumption, environmental specification, type of packaging, and level of integration. PRICE estimates are also based on schedule parameters such as months to first prototype, manufacturing rate, and amount of new design. More detailed discussions of the PRICE acqusition estimating capability are provided in Appendix L.

Recently RCA has expanded PRICE to include a life cycle cost capability. Called PRICE L (see Appendix L), it provides a methodology for rapidly computing support costs for many varieties of systems. Required user inputs include factors for equipments employment, deployment, maintenance policy and levels of support capability, equipment and maintenance locations, and total years to the life of the system. All other required inputs are developed by the PRICE model or directly input by the user at the user's option. This linkage to the basic PRICE acquisition model suggests that the LCC

basis for PRICE L is a set of support cost factors applied to acquisition costs.

These inputs that are either calculated by the PRICE acquisition model or directly input by the PRICE L user include:

(1) Line replaceable unit (LRU) MTBF
(2) Mean time to repair for LRUs and modules
(3) Unit costs for LRUs, modules, and parts
(4) Development cost
(5) Non-recurring production costs
(6) Number of module and part types
(7) Fraction of non-standard parts
(8) Cost for contractor repair of LRUs and modules
(9) Cost for LRU test set and for combined LRU and module test set
(10) Learning curves for LRUs, modules, and parts
(11) Duration of development and production periods
(12) Shipping weights for LRUs, modules, and parts
(13) Storage cubes for LRUs, modules, and parts
(14) Floor space required for LRU test sets and LRU and module test sets

Because these data inputs are quite extensive, it seems likely that a PRICE L user would tend to avoid directly inputting these values and would instead opt for providing the basic inputs to the PRICE model and letting the PRICE model calculate the above listed 14 inputs to PRICE L.

The life cycle cost outputs of PRICE L are presented in Table 24. PRICE L does not calcualte costs for field testing, operation, site facilities, anticipated system or modification changes, and government adminstration. If values for these costs are known to the user, they can be throughput into the model and printed out with the caluculated life cycle costs and included in the LCC totals. Appendix L provides a sample PRICE L life cycle cost output sheet.

Table 24. PRICE L BASIC OUTPUTS

Output Category	Discussion
Most Cost Effective Maintenance Concept	PRICE L assesses 19 alternative maintenance concepts and identifies the lowest cost concept and prints it on the output sheet.
Cost Effective Maintenance Concept List	All 19 maintenance concepts are ranked from lowest cost to highest and printed out along with a ranking number equal to 100 for the lowest cost concept and higher numbers for the other concepts.
Development Costs	Dollar values for development costs in the following categories are printed: equipment, support equipment, manpower, supply, supply administration, contractor support, and other.
Production Costs	Dollar values for production costs are printed in the same categories as given above for development costs.
Support Costs	Dollar values for support costs are printed in the same categories as given above for development costs.

The first two blocks of output information identified in Table 24 relate to the most cost effective maintenance concept from among the 19 presented in Table 25. The output sheet identifies which of these is least costly, and ranks all 19 concepts from lowest to highest cost. The lowest cost concept carries a ranking number of 100, and the other highest cost concepts carry numbers greater than 100 in proportion to the excess of their costs over the costs of the lowest cost concept. Thus, if concept number 15 were the lowest cost concept it would carry a ranking number of 100, and if concept number 5 carried

Table 25. MAINTENANCE CONCEPTS ASSESSED IN PRICE L

Maintenance Concept No.	Maintenance Concept
1.	LRU discard at failure.
2.	LRU repair at Organization. Module discard.
3.	LRU repair at Intermediate. Module discard.
4.	LRU repair at Depot. Module discard.
5.	LRU repair at Organization. Module repair at Intermediate.
6.	LRU repair at Organization. Module repair at Depot.
7.	Repair LRU to piece part at Intermediate.
8.	LRU repair at Intermediate. Module repair at Depot.
9.	Repair LRU to piece part at Depot.
10.	Repair LRU to piece part at Organization.
11.	On-equipment repair to module. Module discard.
12.	On-equipment repair to module. Module repair at Organization.
13.	On-equipment repair to module. Module repair at Intermediate.
14.	On-equipment repair to module. Module repair at Depot.
15.	LRU repair at Contractor Depot. Module discard.
16.	On-equipment repair to module. Module repair at Contractor Depot.
17.	LRU repair at Organization. Module repair at Contractor Depot.
18.	LRU repair at Intermediate. Module repair at Contractor Depot.
19.	Repair LRU to piece part at Contractor Depot.

a ranking number of 346, you could interpret the quantitative relationship between the two concepts as: number 5 is more than three times as costly as number 15. (See Appendix L for a sample maintenance concept list.)

The development costs, production costs, and support costs identified in Table 24 are displayed on the PRICE L output sheets in a format like Table 26.

Further details on the PRICE L model are discussed in Appendix L, but this does not include the equations on the internal model configurations which yield the cost estimates because PRICE and PRICE L are RCA proprietary instruments.

6. Subjective Expert Judgment Approach

Throughout acquisition cost and support cost estimating, subjective expert judgments play a role. Regardless of the methodology, an expert judgment can change the value of a variable in an equation. These judgments introduce real world value judgments into the mechanical mathematical processes of computing costs.

E. DATA AND MANAGEMENT SYSTEMS

The support cost data and management systems available to contractors are usually restricted to data from the Air Force and the Navy on their own equipments. This restriction is one reason why contractors are often willing to engage in cost methodology studies for the Services, because the contract may permit them to gain access to data on other contractors' systems.

Internally contractors have their own engineering level data available to develop early cost estimates, but these data are proprietary and difficult for other firms to acquire. It is, of course, primarily useful for acquisition cost estimates,

Table 26. COST MATRIX FORMAT FOR PRICE L

Cost Elements	Cost Categories			
	Development	Production	Support	Total
Equipment				
Support Equipment				
Manpower				
Supply				
Supply Administration				
Contractor Support				
Other				
Sub-Total				
Throughput Costs				
TOTAL COSTS				

not support costs. These latter costs are primarily housed in the Services reporting systems identified in the earlier chapters.

F. SUMMARY

Contractor cost estimating methodologies range throughout the various forms of support cost estimating available. At the contractor equipment-producer level, engineering and analogy methods are most prevalent, while at the contractor aircraft-producer level, accounting and parametric regression methods prevail. All of these methods and others interact through iterative processes and this interdependence characterizes contractor cost estimates. The general contractor view of these

policies is that the Services do not ask for enough support cost data early enough and at a low enough level of detail. Therefore, contractors doubt that support costs on equipments like avionics are major design influencing factors in the government's acquisition decisions.

Chapter IV

EVALUATIONS OF SUPPORT COST MODELING METHODOLOGIES UTILIZED BY THE SERVICES AND CONTRACTORS

A. INTRODUCTION

There are two broad classes of scientific models that represent all the cost estimating approaches discussed in the previous chapters--deterministic models and stochastic models. Deterministic models do not explicitly include uncertainty in their structures, stochastic models do. A common class of deterministic models is the accounting model (AFLC-LSC, Navy LCC, CRIER) that accepts all input values as precise and sums model elements to produce cost sub-totals and totals. A common class of stochastic models is the parametric regression model (Navy F-18 top level, Avionics Laboratory-sponsored research, Grumman-Lockheed Georgia contract) that explicitly incorporates uncertainty into its structure and provides measures of the ranges of uncertainty attached to its cost products. These two model classes constitute the background against which the various modeling approaches presented in the earlier chapters may be assessed. The purposes of these assessments are to:

(1) describe the fundamental similarities and differences between and among the several methodological approaches;

(2) assess the usefulness of the various models for estimating component support costs, especially early in the acquisition process;

(3) identify whether the modeling techniques are appropriate for estimating point values of support costs;

(4) identify whether the modeling techniques are appropriate for trade-off comparisons between or among alternative components.

B. REGRESSION MODELS

1. Overall Assessment

The strong appeal of a regression equation estimating technique is grounded in its ease of application. Once the equation is created, its use is merely a matter of placing a few variable values in the equation and processing the equation to calculate the cost dependent variable. The unique advantage of a regression equation is that it permits formal estimates of the degree of certainty associated with its calculated results. Among the requirements that must be met for a regression equation to be useful are that the data must be available in the categories presumed to be relevant, and the relevant categories must be selected based on prior expert knowledge of the real functional relationship between support costs and the cost drivers (independent variables).

The avionics support cost regression equations at the component level that we examined in our research suffered both from a lack of relevant data availability and from a lack of expert knowledge of the real cost drivers for specific types of component equipments. These two requirements have appeared to be interrelated in these studies. Theoretical discussions of the relevant cost drivers are brief and infrequent. The cost drivers put forward as relevant have frequently been a function of the data available. Independent variables seem to have been selected in some instances because data were available on their magnitude, not because the variables were logically related to the support costs of component equipment. This latter condition is an unavoidable characteristic of empirical investigations but its unavoidable nature does not make it either desirable or acceptable. As long as data are poor, the

theoretical assessment of relevant cost relationships will be inhibited. This fundamental fact offers some justification for the substantial scepticism that we encountered in our research concerning the usefulness of currently available support cost regression equations for avionics components.

Another form of these interrelated problems of the lack of relevant data and the subsequent lack of theoretical analysis of the real cost drivers is that regression equations are sometimes processed merely to ascertain which independent variables provide the highest coefficient of correlation.

The great danger present in basing the theoretical relationship to be tested on the data available is that the real theoretical relationships may be entirely missed or obscured because the data do not actually reflect the real functional relationships. A theoretical appreciation of the functional relationship between costs and drivers must be the basis for a cost estimating regression equation.

Interestingly, part of the data problem has been with respect to the dependent variables (the support costs) in the regression equations, as well as with the independent variable cost drivers. If the cost data being "explained" by the regression equation do not represent the real costs of a particular support activity, then the equation provides inaccurate coefficients which misspecify the true relationships between the cost drivers and the costs.

Some analysts have suggested that regression equations are not useful for component support cost estimates because the real cost drivers are not only physical design and performance characteristics, but also are environmental constraints like maintenance and operating policies. It is argued that maintenance and operating policies are difficult to quantify. Under some circumstances this concern is unsubstantiated by a careful consideration of its implications. Comparisons between

alternative avionics equipments subject to the same maintenance and operating policies are unaffected by the absence of a variable to represent these policies. In this case, the policies are like fixed costs and are the same for all equipments. But if alternative maintenance or operating policies are the distinguishing characteristics differentiating one avionics equipment from its competitive alternatives, it is possible to treat the different policies in the regression equation through the use of dummy variables. This has limited usefulness and does not permit small discrete differences to be regressed in the equations. Another approach is to use proxy variables that can be quantitatively measured and which approximate the effects of maintenance and operating policies. Suitable proxy variables have not yet been identified in the literature. These approaches may be especially appropriate when the cost being estimated, the dependent variable, is total maintenance cost which incorporates elements of both fixed and variable costs.

2. The Navy F-18 Regression Equations

The F-18 top level system equations do not estimate support costs at the component level. The costs are estimated for the total weapon system in several categories including enlisted maintenance and operating personnel, depot component rework, replenishment spares, and other consumables. These total system costs are then allocated to two-digit work unit codes with the allocation factors based on historical cost experience on the F-4J TMS aircraft. This methodological variation offers interesting potentials for early acquisition cycle component cost estimates, although not necessarily with the specific cost elements used for the F-18.

As explained in Chapter II, the dependent variable costs are taken from the NARM program factors categories. The NARM provides the data base for component rework, replenishment

spares, and other consumables costs for several aircraft which are regressed as dependent variables against aircraft characteristics' variables. The difficulty with these cost data is that the NARM dollar values may not represent actual expenditures of resources in the various cost categories. The costs recorded in the NARM for budgeting purposes may bear some relationship to actual work performed on avionics equipments or aircraft,[1] but the relationship may be obscured by the requirements of the budgeting process.

The component rework equation could not produce both a high coefficient of determination and a theoretically reasonable set of equation variables according to McDonnell-Douglas aircraft research reports.[2] It seems that the equation does not represent the real relationship between component rework costs and its drivers. Nonetheless, the DSARC II submission of cost estimates used the equation. It contains a term that is empty weight of the aircraft divided by mean flight hours before failure (MFHBF). This term lacks intuitive appeal as an obvious logical cost driver for component rework, or anything else. The coefficient of determination may be low because of trouble on the dependent variable cost side of the equation; the budget-constrained NARM component rework collars in the regression data base may not be a true measure of depot work performed. If it is not, then the coefficient of determination between it and physical characteristics' independent variables may have little meaning.

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[1]Component rework includes the cost of repairing components at the depot, both scheduled and unscheduled, and the majority of this activity is for avionics components. Other consumables consist of non-repairable consumable material used for organizational and intermediate maintenance, and repair of repairables. Most of these materials are consumed by avionics WUCs.

[2]C.E. Earnhart, *Improved Life Cycle Cost Estimating*, Report No. MDC A4563, McDonnell Douglas Aircraft Company, December 22, 1976.

Replenishment spares costs were estimated with an equation involving avionics suite, propulsion, and airframe acquisition costs, as well as empty aircraft weight, aircraft velocity maximum, and MFHBF as the independent variables. Again, one of the terms is empty weight divided by MFHBF, without any explanation of the supposed theoretical relationship between this term and replenishment spares. Although the equation (shown in Chapter II) was used to estimate DSARC II costs, subsequent research by McDonnell-Douglas on the equation leads them to reject it because of data deficiencies in the historical replenishment spares cost data, which was determined to have been "developed by an allocation technique."[1]

To overcome the cost data difficulties present in the NARM budget-constrained data, this approach could be pursued using VAMOSC Maintenance Subsystem Data for costs. Because of the greater detail for costs available in the VAMOSC reports, separate equations could be prepared for organization, intermediate, and depot maintenance. Separate scheduled and unscheduled maintenance equations could be prepared for organization and intermediate maintenance, and for NARF and commercial depot actions if desired.

Given that theoretically acceptable cost data can be obtained, this only gets us as far as total weapon system cost estimating equations. These are desirable for early acquisition cycle estimates because they require a few data inputs. Our discussions with contractors reveal that as early as DSARC I, airframe contractors could provide independent variable values for weight, maximum velocity, MFHBF (through engineering analysis of analogous systems), and acquisition costs for airframe, propulsion, and avionics.

The allocation of these estimates to WUC could be accomplished as in the F-18 case by picking a single operational

[1]*Ibid.*

aircraft that is most analogous to the proposed aircraft. Then, use of the two-digit VAMOSC WUC values for the various costs as proportioning factors would allocate the total weapon system cost estimate to WUCs on the proposed aircraft.[1]

A more sophisticated version of this approach would be to select various WUC analogous equipments from the entire inventory of avionics equipment, regardless of whether the equipments are on one or several aircraft. Assuming that they are on several aircraft, the WUC costs for a cost category, such as depot maintenance, could be added to form a total, then each WUC cost, perhaps from different aircraft, could be turned into proportioning factors for the new F-X aircraft proposal. This multiple aircraft analogous WUC selection, forming the basis for the total F-X equation allocations to WUC, would enjoy the benefit of tailoring each WUC equipment to its closest analogy.

This tailoring approach has another potential. It could be used to trade-off alternative types of avionics systems. Assume that one F-X proposal at DSARC proposed an F-18 avionics suite as most analogous. Using the F-18 VAMOSC cost data, the F-18 based proportioning factors could be used to allocate total weapon system regression estimates. An alternative avionics suite, say on the F-16, could be substituted to develop the proportioning factors. The differential impacts, if any, of the two avionics suites on the proportioning factors would provide an initial comparative trade-off potential among alternative avionics suites early in the acqusition cycle.

The approach to component support cost estimating represented by the Navy's F-18 total system regressions, followed by analogy WUC allocation factors, is useful both for point estimating and for trade-off comparisons. The problems in the Navy system could be overcome with improved data sources.

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[1]This procedure as applied to the F-18 is explained in Chapter II.

3. Avionics Laboratory Research

The Air Force Avionics Laboratory avionics support cost estimating regression equations currently available are largely exploratory results not intended to actually be used for cost estimating in their present forms. The major difficulty with the equations is the dependent variable cost data validity. The cost data are simply incomplete, so the equations are qualified as being representative of the form that such work might take in the future, but not representative of currently useful regressions.

The in-progress work for the Avionics Laboratory by Westinghouse is intended to produce a "predictive operation and maintenance cost model" at the avionics subsystem level. This model is to be composed of equations that are not peculiar to any one functional category of avionics equipment, but instead will apply to any piece of equipment without specific characteristic uniqueness identified to that equipment built into the equation. This is a requirement that seems difficult to fulfill. The underlying assumption here is that there are certain key cost-driving design parameters that are common to all avionics equipments in the inventory. If this assumption were correct, equations common to all the avionics inventory could be developed, given reliable cost data for the regressions and accurate identification of the correct cost drivers. But then these are the requirements of any valid regression model. It is interesting that the 1974 Avionics Laboratory-sponsored avionics support cost research suggests that general across-avionics system equations are not valid because of the great differences among alternative avionic systems.[1] With specific reference to airborne array radar cost analysis, the 1974 report concludes that

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[1]E.N. Dodson, S.F. Kornish, *Cost Estimating Relationships for Airborne Array Radars, FLIRs, and Avionics Logistics Support (U)*, AFAL-TR-75-15, Vol. II, Air Force Avionics Laboratory, Wright-Patterson AFB, Ohio, August 1975.

"In short, a sample of current radars is a distinctly heterogeneous set, and aggregated cost comparisons must be made with great care. Again, the recourse is to carry out cost analysis at finer, disaggregated levels of detail so that the unique (and common) features can be explicitly treated." This seems to contradict the spirit of the current Westinghouse effort to develop non-unique across-avionics-systems regression equations for support costs.

C. ACCOUNTING MODELS

1. Overall Assessment

Accounting support cost models are deterministic models that add up costs at detailed equipment levels. Early in the acquisition cycle for a new F-X aircraft, the only source of data for such a model is analogy to existing systems. The successful use of analogy data in both the Navy and the Air Force versions of support cost accounting models until recently has been inhibited by multiple data systems that produce difficult to reconcile data. The recent addition of the VAMOSC Maintenance Subsystem in the Navy greatly enhances the Navy's capability for analogy component costing using accounting models. The Air Force is still developing an equipment-level LRU-SRU support cost reporting system to complement its weapon system-level OSCER system. Complicating the data even further has been the lack of a direct linkage between organizational and intermediate maintenance WUC reporting categories and depot maintenance National Item Identification Numbers (NIINs).

The frequently used accounting models like the AFLC LSC model and the Navy's LCC model have another characteristic that weakens their usefulness as design and performance discriminators. Logistic support costs are computed as functions of logistic reliability and maintainability parameters in these models, but performance and design characteristics play no role

in the functional relationship between support costs on one side of the equations and the cost drivers on the other side. Variables like type of materials, size, speed, and range have no role to play in these estimates.

A final difficulty with accounting models is inherent in their deterministic natures. Because there are uncertainties surrounding the data, the accounting-type model is at a disadvantage for lacking techniques that can estimate the ranges of uncertainty attached to costs produced as accounting model outputs.

2. AFLC LSC Model

The mechanics of the LSC model have been extensively displayed in Figures 1 through 6 in Chapter II. Given the weaknesses of the model, cost estimates based on analogy estimates early in the acquisition cycle are of limited usefulness. Once actual test data become available, however, the LSC model takes on a different character. Given actual data, it provides a convenient set of processing and organizing equations for the cataloguing of logistic support costs.

Its usefulness as a source selection cost model seems limited as long as analogy data are limited. Without a capability in the Services and OSD for verifying the LSC model inputs received from contractors as the source selection approaches, the source selection cost estimates have no discipline external to the contractor's decisions imposed upon their magnitudes.

The Air Force has attempted to impose such discipline in the F-16 program by utilizing selected LSC equations as the basis for what is called the Target Logistic Support Cost (TLSC) program mentioned in Chapter II. The data to input into the equations are derived at the time of the 3500-flight-hour test for the F-16 aircraft. But this is a test-based system and

would not be available in the conceptual development phases of the acquisition cycle.

3. The Navy LCC Model

The variables and equation structures for the Navy LCC accounting model are presented in Appendixes G and H, and a discussion of the model appears in Chapter II. It has no differentiating characteristics as an accounting model that prevent it from being subject to the same criticisms as the Air Force LSC accounting model. However, the data issue offers some promise of resolution here, because the Navy VAMOSC Maintenance Subsystem can provide historical data on analogous aircraft subsystems to input into the model.

4. The CRIER Accounting Model

This model was developed by a panel of avionics experts specifically to estimate avionics equipment life cycle costs including support costs. The equations are more numerous and complex than those in the AFLC LSC model and the Navy LCC model.[1] The equations are presented in an excerpt from the CRIER users manual in Appendix K. They cover acquisition, research and development, and operating and support costs. This makes them more extensive in coverage than the AFLC-LSC equations.

D. OTHER SERVICE MODELS AND APPROACHES

Other component level models that can be utilized to estimate some elements of support costs include the LCOM simulation model, the Navy Level of Repair Analysis and Air Force Optimum Repair Level Analysis models, and the MOD-Metric type spares models.

[1] See Table 7 in Chapter II for a listing of the operating and support cost elements for which separate accounting equations exist in the model, including equations for replenishment spares, depot labor and material, and organization and intermediate maintenance in several categories.

The LCOM simulation maintenance manpower model offers a useful methodological approach to estimating the base level maintenance manpower requirements of a weapon system under development. In its current configuration the LCOM is a large model that requires massive input specifications for the operational and maintenance environments and the comparability analyses of specific equipments, including avionics. The qualification that must be made to the use of the model is that it is a complex time-consuming process for which the output is only one of several elements of support costs. Nonetheless, the Air Force is currently using LCOM simulations on all new aircraft programs.

Level-of-repair models like ORLA and LORA can provide the capability to determine the least cost level of repair policy for new components on F-X aircraft. The model simply adds up the various costs of three maintenance alternatives for each line replaceable unit (LRU) on a proposed aircraft--discard at failure, repair at base, repair at depot--and then identifies the least costly for each LRU. The data requiresments for these models are extensive, although it is possible to operate them by analogy data. The usefulness of such an exercise early in the acquisition process is uncertain. Given two competing maintenance concepts the models could assist in producing a least cost output, but the magnitudes of the analogy-derived costs would be useful only as comparative trade-off measures, not as point estimates.

Spares inventory management models like MOD-METRIC can assist in reducing the number of spare items required to keep a system operational. These models can determine optimal spares stock levels in a multi-item, multi-maintenance echelon environment for recoverable items. The heart of the approach demands substantial data and systems definition, including subassembly removal frequencies, average resupply times, NRTS

rates, and other similar detailed inputs by detailed seven-digit WUC equipments. The models can operate with analogy data early in the acquisition cycle to determine the impact of alternative maintenance concepts on spares requirements. If analogy is used, considerable time and effort are required to accumulate and input the requisite data.

E. CONTRACTOR ENGINEERING APPROACHES

The fundamental contractor approach of engineering build-up and analogy cost estimates for acquisition costs is unlikely to be useful outside the contractor environment. Engineering and management expertise is a cumulative body of knowledge acquired over time that would be expensive to replicate and difficult to maintain outside the contractor environment. In addition, the outputs of these approaches are acquisition cost estimates and reliability and maintainability estimates which must then be input into a support cost model. As a result, the basic contractor approach is unique to the contractor environment.

F. SUMMARY

The currently available versions of the two fundamental avionics support cost estimating methodologies, regression and accounting models, do not provide useful avionics support cost estimates early in the acquisition cycle. Data system limitations have particularly hampered regression model developments. Accounting models have been of little use early in the acquisition cycle because of the dual effect of data system limitations and the requirements for substantial data detail. Analogy inputs to accounting models have been equally hindered by the absence of reliable comprehensive data bases.

Other estimating models attack the support cost problem piecemeal, only providing estimates of a specific support cost category at substantial costs in time and effort.

Chapter V

MODELING APPROACHES FOR OSD

A. INTRODUCTION

The prior chapters present a comprehensive review and evaluation of the methodological approaches to fighter aircraft avionics support cost estimating that are currently used by the Services and weapon system contractors. These approaches differ significantly in data requirements, design and performance sensitivities, and degrees of accuracy. They also differ in another important respect that is relevant to the assessment of methodological approaches at the CAIG level--whether they are primarily suited to estimate point values of support costs or for comparisions of alternatives in trade-off studies. Briefly discussed in Chapter I, this issue is critical to the recommendations of specific methodologies and approaches useful to the CAIG, and as a result will be examined in greater detail here.

Ideally an estimating technique should be able to produce cost values that are simultaneously valid for both point cost and trade-off study estimates. None of the current Service or contractor techniques possess this ideal characteristic. The difficulty inherent in using a single model for both types of estimates is that the point and trade-off models may be sensitive to different independent variables.

For a point estimate of the support costs for a piece of avionics equipment it may be appropriate for an estimating equation to focus on independent variables like MTBF, weight, and volume of the avionics equipment. By examining historical

data that include several different avionics equipments in a single functional category, like radar antennas, we may be able to develop estimating relationships between cost and MTBF, weight, volume, and so on. However, if we wished to make the source selection and other early decisions based on life cycle costs, we would require independent variables that would permit us to discriminate among and between alternative avionics components. MTBF, weight, and volume would likely be characteristics that the competing avionics contractors would have to design to. If all designs submitted to source selection are identical with regard to these characteristics, then some other set of variables would have to be identified that could differentiate one potential radar antenna from another with respect to support costs.

The capabilities and sensitivities of various modeling approaches were treated more fully in Chapter IV, but here we are concerned with the fact that different methodologies and models are suited for different purposes.[1] These differences require us to recommend that the CAIG use different models for point estimating and trade-off comparisons.[2]

[1]This problem is not unique to avionics cost estimating. The entire economic theory of cost abounds with discussions of the difficulties of taking micro (specific piece part level detail in avionics equipment) data and expanding that data to produce macro (total avionics system and total weapon system level) data. The uncertainties present in the micro data make the expansion to macro data difficult if not impossible. Theoretically it is entirely possible to do so, but practically the estimating tools and techniques simply are not capable of making the transfer from mirco to macro. The uncertainties in the data introduce what is sometimes called the "fallacy of composition" in going from micro to macro data, which simply means that the functional relationships developed for the micro data may not hold when expanded to the macro level.

[2]Electronic versus mechanical antennas of the same aperture provide an example of the requirements of different models for different independent variables. Aperture may be a reliable variable to make point estimates of support costs for radar antennas over a fifteen year life cycle; but, if the apertures of the two competing antenna designs prior to source selection are the same because they were designed to government requirements, then aperture cannot be used to distinguish between the two designs. (Continued on page 185).

B. ESTIMATION MODEL 1 (EM1)

An estimation model that would be useful for validating the magnitude of support cost estimates can be constructed along the lines of bottoms-up and analogy estimates used by contractors. EM1 is a specific application of this bottoms-up approach. The model is described in terms of the Navy VAMOSC Maintenance Subsystem (MS) component equipment data, because this seems to be the most detailed data available. Similar component level data are not currently available in Air Force data systems, including OSCER, without a substantial analysis and gathering effort. The Navy data include base, intermediate, and depot level manhour and material costs, replenishment spares, and spare parts support costs, at the five-digit WUC level of detail.

In the Navy VAMOSC MS system, avionics equipments down to the five-digit level are identified according to physical characteristics. For example, the AN/APR 25 radar detector set is WUC 76660, and is made up of the following five-digit WUC elements:

(1) analyzer, WUC 76661
(2) azimuth indicator, WUC 76662
(3) threat display unit, WUC 76663
(4) preamplifier, WUC 76664
(5) receiver adapter, WUC 76666
(6) filter, WUC 76667
(7) interference blanker, WUC 76668.

These elements can be characterized according to the following kinds of categories as appropriate:

(1) power levels drawn at peak and off-peak uses
(2) number of pieces

(cont'd) Some other variables must be found to explain the differences between the two designs, variables such as the number of antenna elements and the number of subcomponent interfaces within the antennas.

(3) weight, volume, density
(4) linkages to other components
(5) number of geometric elements in a frame
(6) scanning rate.

Using this bottoms-up approach, all the existing five-digit WUC equipments can be identified according to their physical characteristics and established as a detailed analogy data base.

When considering the avionics suite for a new proposed F-X aircraft, the avionics components in the analogy data base that are most like the components in the proposed F-X suite are identified, and in effect an avionics suite is built-by-analogy from the existing data base of avionics equipments. Engineering advice may be required in constructing the analogy avionics suite since the decisions as to which equipments from the data base are appropriate analogies are largely technical engineering decisions.

The next step is to price out the support costs of the list of items that make up the analogy F-X avionics suite, and this can be accomplished by examining the VAMOSC MS historical data for those existing equipments. For equipments that represent an extension of or are more technologically advanced than an existing component, each individual equipment characteristic must be examined. Each characteristic (power, weight, scanning rate, etc.) must be related to maintenance cost and spares requirements. Relationships such as these can be developed through the seven-digit VAMOSC data base, but this will take engineering judgment as well as computational effort. For a new avionics component for which there are no analogies in the judgment of the engineers, special analyses would have to be done. In the opinion of avionics experts at the various contractor firms we visited, there is little in the way of avionics equipment that is so radically new that an appropriate analogy equipment cannot be found for it.

The analysis technique described above could be utilized at a high level of WUC aggregation, say the two-digit level, for grosser estimating. Thus, an entire two-digit avionics equipment would be described by physcial characteristics, related to support costs in the VAMOSC MS report, and would constitute an element in a two-digit analogy data base.

This EM1 model is based on the following logical assumptions:

(1) Avionics can be viewed as a set of functions to be performed, and this set is relatively constant over time. Although specific equipments to perform a function may change, the function remains.

(2) Existing sets of equipments currently perform these functions and can be used as analogy building blocks with which to construct a proposed avionics suite for an F-X aircraft.

(3) Engineering technology is understood by avionics experts, and any proposed technological advances are well integrated into the experts' understanding and perceptions. Experts therefore can make reasoned judgments about appropriate analogies and deviations from the current system.

(4) Through the EM1 process we can build a new avionics suite on paper, then price its support for maintenance and replenishment spares through the data potentials in the VAMOSC MS systems. The bottoms-up approach is the procedure contractors use for preparing acquisition cost proposals, and is the process that can be used to develop support costs if given the VAMOSC data for all possible equipments. The advantage that OSD has over the contractors in this respect is considerable, because the data availability is substantially greater in the area of support costs for OSD than for contractors.

(5) This procedure can be used for DSARC 0, I, II, or III, or any other. The difference among uses at different DSARC milestones is that greater uncertainty is inherent in the support cost estimates the earlier in the process you begin. At DSARC 0 or I you may be working at the two-digit WUC level, while later the level may expand to five-digit WUCs, if desired.

(6) There is nothing that is novel about the methodology of this approach, it has been the basis for contractor acquisition cost estimates for many years. The

(6) availability of support cost data at the detailed WUC level in the Navy VAMOSC is new, however, and this is what makes this approach a potential that will exceed the contractor support cost estimating capabilities in the bottoms-up or analogy mode.

C. ESTIMATION MODEL 2 (EM2)

An estimating model for avionics support costs that could be termed the "traditional" approach is to prepare avionics regression equations that have support costs as the dependent variables and acquisition costs as the independent variables, perhaps with MTBF as an additional independent variable. Although "traditional" in the sense that such equations have been attempted before, the results have not been fruitful. However, given one conceptual assumption, the reason that the traditional approach has not been fruitful previously lies in the inadequacy of historical data, not in the inadequacy of the analytical methodology.

The conceptual assumption that must be made is that support costs, maintenance at all levels, and spares and repair parts support, are a function of acquisition costs. Thus the fundamental equation we hypothezie as representing support costs is, for a maintenance cost example,

$$Y = f(X_1) ,$$

where: Y = annual maintenance cost of a two-digit WUC avionics equipment

X_1 = acquisition cost of the two-digit WUC avionics equipment.

This is exactly the form of equation utilized in the recent General Research Corporation work done for the Air Force Avionics Laboratory. As explained in Chapter IV earlier, they based their data on the Air Force IROS system, which is deficient as explained in Chapter II. However, the availability of Navy VAMOSC Maintenance Subsystem data presents the opportunity to replicate the GRC approach with more complete maintenance data.

The assumption that support costs are a function of acquisition costs is based on a further assumption that acquisition costs are adequate proxies for the real physical design and performance characteristics that are the real support cost drivers. Given this assumption as valid, the simple tradional regression approach may be acceptable. What it is acceptable for is the point estimation of avionics support costs; that is, an estimate of the actual dollar value of future support costs. However, the simple independent variable of acquisition costs provides little discriminatory power between or among alternative avionics systems. The addition of another independent variable like MTBF, X_2 in our expanded fundamental equation below, seems to add little explanatory power in the equations pursued in the literature.

$$Y = f(X_1 X_2)$$

where: Y = annual maintenance cost of a two-digit WUC avionics equipment

X_1 = acquisition cost of the two-digit WUC

X_2 = mean time between failure.

However, the detailed Navy VAMOSC data offer potential estimating equations with enough uniqueness to discriminate among systems.

The approach is to continue to utilize acquisition cost as the prime independent variable; however, separate estimating equations are produced for base, intermediate, and depot maintenance and replenishment spares, for each two-digit WUC equipment. The costs of these categories are available in the VAMOSC system. Each of the costs becomes a dependent variable in a set of estimating equations. Historical data for avionics two-digit WUC equipments are collected for each cost category, then regressed against acquisition costs and MTBF or BCM rates. This approach disaggregates the dependent variable for maintenance costs. With a separate equation calculated for each maintenance cost,

the uniqueness of the base, intermediate, and depot maintenance relationships can be captured in the coefficients of the regression equations. When combined into a single maintenance cost, these unique relationships are masked and perhaps lost.

During the acquisition phases prior to DSARC 0 or DSARC I phases of acquisition, when cost estimates are at an early level and MTBFs not yet specified in most cases, an OSD analyst equipped with three maintenance equations for WUC 72 could engage in the following analysis. Fix the MTBF of the avionics equipment at one value, perhaps the one desired by the sponsoring Service, or the suggested improvement over the old WUC 72 system, and insert alternative acquisition costs into the three maintenance equations, one for organization, one for intermediate, and one for depot level maintenance. This would provide a range of maintenance support costs. Contractor estimates could immediately be checked to see if they are in the relevant ranges. Because the maintenance costs are disaggregated into three components, the sensitivity of each element of maintenance costs could be elevated. A high acquisition cost might produce relatively high organization and intermediate costs but low depot costs, while a low acquisition cost might produce relatively high depot costs but low intermediate and organization costs. The sum of the three elements would yield a total maintenance cost that could permit better discrimination among alternative avionics systems than a single equation for total maintenance costs that did not reflect the different relationships at different maintenance levels. This would have to be tested, but the possibility exists that this traditional approach, combined with VAMOSC detailed data, could yield not only improved point estimation models, but also improved trade-off discrimination models.

D. ESTIMATION MODEL 3 (EM3)

A specific analogy WUC regression model would combine elements of the bottoms-up EM1 approach and the traditional EM2

approach. The procedure would be to first establish an avionics data base that contains physical data characteristics of avionics equipment--size, weight, number of parts, and so on. Through the VAMOSC maintenance subsystem in the Navy, detailed cost data are available for specific pieces of avionics equipment. Given the physical characteristics data and the avionics support cost data, it becomes possible to run regressions on selected pieces of avionics equipments with organization, intermediate, and depot level maintenance costs, and replenishment spares costs, as dependent variables, and physical equipment characteristics as independent variables. These physical characteristics are assumed to be the actual cost drivers behind equipment support costs.

To use these data bases as analogy parametric data bases, the following procedure is followed. Assume a new F-X aircraft is to have an avionics suite composed of equipments that perform identifiable avionics functions. These functions can be identified by the two-digit WUC categories. Take any one of the two-digit WUCs, such as WUC 71, radio navigation equipment. An engineer or other knowledgable person can select various equipments from the physical characteristics data base that are the closest analogies to the F-X WUC 71 equipment. Then, the support costs for these closest analogy equipments can be extracted from the VAMOSC MS data base. Now, regression equations peculiar to the new F-X WUC 71 requirement can be produced, using the physical characteristics from the physical data base as independent variables and the Navy VAMOSC MS cost data as dependent variables. By combining analogies selected by engineering expertise, with parametric estimating techniques, a set of equations can be tailored to the requirements of the new F-X aircraft.

This tailoring capability is the unique and promising feature of this approach. Each time a new F-X aircraft is proposed, a new set of closest analogy regression equations can be produced

from the data bases. This introduces flexibility into the usually static regression technique.

The construction of the avionics physical characteristic data base is obviously a critical assumption for the development of this technique. Another important assumption is the availability of WUC data at the specific equipment level. As explained earlier in Chapter II, these data are currently available in the Navy. To maintain the maximum flexibility of this approach, the data bases would need to be updated as new equipments joined the inventory. This updating should be a small recurring task once the initial data bases are constructed.

This tailored analogy regression model approach should provide both point estimates and trade-off estimates of considerable validity at DSARC 0, I, and II. Initially, the physical characteristics as independent variables would provide a trade-off capability between alternative avionics equipments. As the equipments become more and more defined, the equations can serve equally well as point estimators for validation and verification of will-cost estimates. In addition, if two alternative radio devices were at issue for WUC 71 on the F-X aircraft, two different regression equations could be constructed, one for each alternative that was most closely approximated by analogous equipment from the data bases. Then, the support costs could validly be compared because the equations for each alternative would have been developed from the same homogeneous data bases. As both a point and a trade-off estimating technique, the analogy-parametric approach is promising.

E. ESTIMATION MODEL 4 (EM4)

The AFLC Logistic Support Cost Model, and other accounting models like it (Navy LCC, CRIER), provide viable alternatives for support cost estimates. The difficulty usually cited is that substantial detail is required to process the model's

equations that are rich in data requirements at the FLU level.[1] Although the data requirement is a consideration in using LSC, it is not one that presents unmanageable difficulties even at DSARC 0 and I.

Analogy again provides a technique that can permit the model to function. By using data on analogous systems, the great detail of the LSC model can be provided at any time during the acquisition process.

F. ESTIMATION MODEL 5 (EM5)

The LSC model could be adapted to parametric regression use by turning its basic equations into regressions and obtaining historical data on each variable. Again, analogy to existing systems, based on expert enginerring judgment, would select analogous equipments to the F-X avionics suite. The development of a massive data base would again facilitate the quick response character of this alternative approach.

To take the example of how the process would be implemented, we can examine spares costing for replenishment spares. Similar approaches would be taken for maintenance and any other desired support costs for which LSC equations exist.

The approach to spares costing suggested here it to take the AFLC LSC model spares equation, obtain historical data on existing aircraft components to insert into the equations, calculate spares costs for each two-digit WUC, then regress these costs against the values of the variables in the equations and obtain regression coefficients which can then be used to compute spares costs for proposed systems in conceptual stages.

The LSC replenishment spares equation for the cost of spares (C) for a single FLU is given below.

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[1]See Chapter II for a discussion of the LSC model's complex equations and data requirements.

$$C = \frac{(TFFH)(QPA)(UF)(1\text{-}RIP)(COND)}{MTBF} \quad (UC)$$

where: TFFH = total force flying hours

QPA = number of like FLUs in parent system

UF = ratio of operating to flying hours

1-RIP = fraction of failed FLUs not repaired in place

COND = condemnations

UC = initial provisioning cost

MTBF = meantime between failure

Each variable above is available in historical data systems for existing equipment. By regressing the calculated replenishment spares cost C against what the LSC model uses as the explanatory variables, we hypothesize that the LSC model equation does in fact capture the relevant influence on replenishment spares cost. Individual data points are provided by calculating C for various pieces of two-digit WUC equipment, say WUC 72, radar navigation equipment.

One advantage of such an approach is that a separate regression equation can be calculated for each two-digit WUC equipment category. The obvious disadvantage is obtaining values of the variables for the proposed conceptual stage equipment. But this is a manageable problem. The values for TFFH and UF will be provided at DSARC I in the preliminary WSPD. QPA drops out of this equation when the equation is used at the two-digit WUC level because there is only one two-digit WUC equipment of category 72 on an aircraft, thus QPA is equal to unity here. RIP could be used as a boundary factor setting limits to the repaired-in-place experience; that is, the equation could be run with RIP = 0 to establish one boundary, and with RIP = 0 or 1 to establish another boundary. This setting RIP = 0 or 1 could also serve as a way of introducing a maintenance concept into the equation, if the maintenance concept were to repair either/or all or more of the equipment in place. COND and MTBF

would be the most difficult equation values for the proposed conceptual system, but these too can be handled. COND can be developed as a factor based on the experience with the equipments used in the regression data base. MTBF can either be specified in the DSARC I MENS as a goal to be achieved by contractors, it can be factored from historical experience, or it can be factored and have an "up-grading" applied to it by engineering experts either at OSD or in the Services.

G. ESTIMATION MODEL 6 (EM6)

The RCA PRICE model has a new life cycle cost capability that could provide an alternative approach to support costing. Conceptually inexpensive in that the model theorizing is already accomplisehd and buried within the proprietary interior of the equations, the PRICE-L life cycle cost model provides a quick response tool. As discussed in Chapter III, the model's outputs are not in standard support cost categories; instead, the model's outputs can serve as inputs to other conventional modeling approaches, such as the LSC or other accounting models.

H. SUMMARY

Table 27 displays the various approaches discussed here. Several modeling approaches are available for avionics support cost estimating at DSARC 0, I, and II. Ranging from the bottoms-up analogy approach that relies heavily on engineering expertise to the RCA PRICE-L that relies on unknown proprietary equations, these approaches are varied in their techniques and requirements. The techniques that mose closely approximate the contractor bottoms-up approaches are EM1, an engineering analogy technique, and EM3, a specific analogy WUC regression model. It is clear that analogies to existing systems provide the closest approximation to the contractor approaches.

The most economical approaches in terms of computation time and set up time would be the EM2 traditional regression equations and the PRICE-L model. Finally, the LSC accounting model approaches provide elements of both analogy estimating in the EM4 model, and regression estimating in the EM5 model. Both however do require considerable data, but the data can be obtained by analogy and used throughout the early stages of the acquisition process.

Table 27. SU

Model	Type	Existing Examples	Re Analyti
Estimation Model 1	Bottoms-up and Analogy	Basic contractor approach after DSARC 0	Initial an engineerin a continua model is b
Estimation Model 2	Traditional regression approach with acquisition cost as one of a few independent variables	GRC models	Initial an existing h base
Estimation Model 3	Regression and Bottoms-up analogy combined	Some contractor research being done to develop such models	Initial en analysis a continual support in data base
Estimation Model 4	Accounting and Analogy	AFLC LSC, Navy LCC, CRIER	Analytical process ma inputs
Estimation Model 5	Regression	None	Initial a to work hi base
Estimation Model 6*	Proprietary Regression (RCA PRICE)	RCA PRICE-L	Initial tr operator, required

*The RCA PRICE model alternative differs from the other alternatives in that the equations are relationships in the equations.

27. SUMMARY OF SUGGESTED MODELING APPROACHES FOR OSD-LEVEL

Required Analytical Support	Lowest Level of Detail in Model	Useful for Point or Trade-Off Cost Estimates	Feasibility for
tial analysis and then ineering judgments on continual basis while del is being utilized	7-Digit WUC Equipments	Point and Trade-off	Not feasible - t
tial analysis of sting historical data e	2-Digit WUC Equipments	Point	Feasible after i research to deve suitable data ba equations
tial engineering lysis and then tinual engineering port input to update a base	7-Digit WUC Equipments	Point and Trade-off	Feasible after i research to deve suitable data ba equations
lytical support to cess massive data uts	7-Digit WUC Equipments	Point and Trade-off	Not feasible - t
tial analytical effort work historical data e	2-Digit WUC Equipments	Point and Trade-off	Feasible after c the basic model
tial training of model rator, same operator uired to input data	7-Digit WUC Equipments	Point and Trade-off	Feasible but va outputs very unc

ons are unknown to the model user. Only RCA knows the equations. This prohibits the user from assessing the fu

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STED MODELING APPROACHES FOR OSD-LEVEL

	Lowest Level of Detail in Model	Useful for Point or Trade-Off Cost Estimates	Feasibility for use at OSD
en n	7-Digit WUC Equipments	Point and Trade-off	Not feasible - too detailed
n	2-Digit WUC Equipments	Point	Feasible after initial research to develop suitable data base and equations
	7-Digit WUC Equipments	Point and Trade-off	Feasible after initial research to develop suitable data base and equations
	7-Digit WUC Equipments	Point and Trade-off	Not feasible - too detailed
t	2-Digit WUC Equipments	Point and Trade-off	Feasible after establishing the basic model
l	7-Digit WUC Equipments	Point and Trade-off	Feasible but validity of outputs very uncertain

del user. Only RCA knows the equations. This prohibits the user from assessing the functional

Chapter VI

SUMMARY AND CONCLUSIONS

A. INTRODUCTION

In the preceding chapters, we have discussed Service and contractor methods for developing avionics component support cost estimates. We placed particular emphasis on the methods appropriate to estimating support costs early in the acquisition cycle. These methods differ widely in their treatments of the pervasive problems of uncertainty that characterize all cost estimating techniques, ranging from the experienced expert judgments of design and reliability and maintainability engineers at the contractor level to the highly aggregated program factors and regression equations used by the Air Force and Navy. We presented our evaluations of these methods and discussed six modeling methodologies that OSD should consider in deciding upon an approach to use for early acquisition cycle avionics component support cost estimates. We conclude that it is feabile for avionics and airframe contractors, the Services, and OSD to estimate these costs early in this cycle.

Before proceding further, we should restate that we assumed OSD has two major needs that require an avionics component support cost estimating capability. First, OSD should have the tools to independently evaluate the support costs estimates that are presented to them by the Services at the various milestones in the DSARC process.[1] This need for independent OSD evaluations

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[1]"Independence is a relative term, because all the cost estimates made for specific equipments must rely on common data (continued on page 200)

raises several issues that require resolution as part of our final assessment of the feasibility of making component support cost estimates for avionics equipments at the OSD level. These issues are:

(1) Using current methodologies, can the Services make and submit component support cost estimates earlier in the acquisition cycle than they do now?

(2) As necessary supporting inputs to the Service estimates, can the contractors make and submit component support cost estimates earlier in the acquisition cycle than they do now?

(3) Finally, if the Services and contractors are capable of making and submitting these estimates as early as DSARC 0 and I, are there tools potentially available to OSD to evaluate these estimates?

The second major OSD need is for making trade-off analyses between and among alternative equipment designs and configurations. This need also raises several issues that require resolution as part of our feasibility determination:

(1) Can trade-off studies be conducted for the total life cycle costs of individual equipments, including the support costs for maintenance at all levels and spares and repair parts support?

(2) Is OSD required to depend upon the Services for trade-off analyses because the tools cannot be developed at the OSD level?

As a result of the research reported in Chapters I through V, we concluded that avionics support cost estimating is feasible at the OSD level to meet both the needs for independent evaluations and for trade-off studies, and we resolved each of the issues raised by these needs as follows:

(1) The Services can make and submit avionics component support cost estimates prior to DSARC II and as early as DSARC I and 0 using current methodologies. Few of

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(cont'd) reporting systems. The independence referred to here is relative to the assumptions of the models and adjustments of the data that go into the models. In these senses, it is possible for OSD to develop "independent" estimates.

the Services estimating techniques are inappropriate for implementation earlier than now performed.

(2) The contractors can make and submit component support cost estimates as early as they are required to do so, including the conceptual study stage prior to DSARC 0, if desired. These contractor estimates are grounded firmly in the accumulated experience of the design and reliability and maintainability engineers in the various companies, and as a result provide a potential foundation upon which the Services' estimates can be built by using the contractor judgments and modeling outputs as inputs into the Service methods.

(3) The availability of tools for avionics support cost estimating at the contractor and Service levels is evidence that tools can be available at the OSD level. Given various levels of resource commitment by OSD, there is no doubt that various estimating tools can be exercised at the OSD level.

(4) Trade-off studies can be conducted for life cycle costs, including maintenance and spares support costs, for individual avionics equipments and functions. The prime requirement for maintenance and spares support costs trade-off analyses, whether at the contractor, Service, or OSD levels, is for consistent cost data. The tools for trade-off analyses exist, it is the availability of cost data that inhibits trade-off analyses.

(5) Because trade-off methodologies exist at the contractor and Service levels, the methodologies can be adopted for use at the OSD level.

Given the feasibility of meeting the OSD needs for avionics component support cost estimates, and given the resolution of the various issues raised by these needs, it is important to recognize that the degree of sophistication of the tools finally adopted by OSD depends upon the OSD commitment to including life cycle costs as important, sometimes controlling, variables in the decision-making on new major system acquisitions. In the course of our research interested personnel in the Services and contractor firms consistently stated that a major OSD decision based on a balanced appraisal of full life cycle costs for a major weapon system would go a long way toward enforcing support cost discipline throughout the acquisition cycle.

Given a clear OSD decision based on life cycle costs, the degreee of sophistication of the final tools that could be adopted by OSD to independently estimate support costs and to conduct trade-off studies could be considerable. The basic data and documentation would be flowing through the contractor and Service costs estimating methodologies and would provide, over time, a body of culmulative evidence that could be used to refine and extend the OSD capabilities.

The evidence at the contractor and Service levels is that equipment level support cost estimating methodologies are interactive and mutually supporting. Currently, OSD is out of the loop of this interaction prior to DSARC II because equipment level support cost estimates are not considered in DSARC 0 and I decisions. As discussed elsewhere in this paper, design decisions made in the conceptual stages long before DSARC II commit seventy to eighty percent of life cycle support costs for a weapon system and its components. Thus, if OSD is to have an influence on the majority of weapon system support costs through DSARC decisions, it must develop a capability to evaluate support costs at the equipment level before DSARC II.

Regardless of the specific support cost estimating techniques employed, estimates prepared early in the acquisition cycle embody large uncertainties. The decision on a specific cost estimating technique to adopt at the OSD level depends largely on the amount of resources OSD is willing to invest to minimize these uncertainties. In turn, the willingness to commit resources to component support cost estimating is in large part a function of the extent to which component support cost estimates will affect the final decisions on major weapon or avionic system acquisitions. The admitted existence of large uncertainties in early acquisition cycle cost estimates should not be interpreted as evidence that such estimates cannot be made managable in terms of their predictive accuracy. Cost estimating techniques that involve explicit measures of

uncertainty provide a means for placing the degree of uncertainty attached to a support cost estimate in perspective.

In the following sections we present our conclusions on techniques that OSD should develop and use to cope with its two major needs for avionics support cost estimates. As discussed in earlier chapters, we believe it is quite feasible to develop estimating techniques that could be employed at all stages of the DSARC process. This is confirmed by the existence of a variety of such techniques at the contractor and Service levels. The decisions on which techniques to develop depend on the degree of uncertainty the user is willing to accept in the outputs of the estimating methodology as reflected by the amount of resources committed to the techniques developed.

B. POINT ESTIMATE METHODS FOR OSD USE AT THE DSARC 0 MILESTONE

This section addresses methods to be used very early in the system development cycle, prior to the publication of an operational requirement document (DSARC 0). It is doubtful if OSD would undertake individual component trade-off analyses this early in the system acquisition cycle; therefore, avionics support cost estimating at the two-digit WUC level should be adequate. Furthermore, we believe that the basic support cost estimating approaches could be the same for DSARC 0 and DSARC I although, as discussed below, some capabilities may exist at DSARC I to develop better estimates than at DSARC 0.

1. Tools to Provide Minimum Required OSD Capability

The EM2 model offers the greatest promise as a method to satisfy the DSARC 0 requirement. This model has the advantage of simplicity and after suitable equations have been developed it should be inexpensive to use and to maintain. The model outputs would contain relatively high degrees of uncertainty, but the values should be sufficiently accurate to support the kind of decision that OSD must make at DSARC 0.

Although considerable uncertainty in output values must be accepted with this model, a substantial effort should be devoted to the preparation of a suitable historical data base and conduct of regression analyses to develop reasonable equations. The Navy VAMOSC data base with data through FY 1977 should be suitable for first stage work in developing an EM2 type model. A preliminary model probably could be developed with the existing data base that contains information only through FY 1976.

Our research indicates that the analysts who develop the OSD EM2 model would be unable to find a comparable data base readily available for the Air Force. However, it should be possible to create an acceptable Air Force data base by using the information available in several AFLC data systems. The current Air Force VAMOSC system (OSCER) is not acceptable for the EM2 model partially because it does not provide avionics support cost information at the two-digit WUC level.

2. <u>Tools to Provide Enhanced OSD Capability</u>

An enhanced OSD capability could be provided by the development and use of an EM3 type model at the DSARC 0 milestone. The major improvement provided by this model as compared to the EM2 is the introduction of engineering judgments with regard to the physical characteristics of a proposed aircraft avionics system. Undoubtably some of these judgments could be made by engineers even as early as the DSARC 0 milestone but we do not consider that these judgments would reduce model output uncertainties sufficiently to justify the use of EM3 at DSARC 0. Admittedly our conclusion is based on intuitive judgments of the nature of the information required for OSD decisions at the various stages of the system acquisition cycle. Nevertheless, we believe that the OSD decision at DSARC 0 would not be sensitive to the marginal improvements provided by an EM3 versus EM2 model calculation.

We conclude, therefore, that an EM2 model capability is adequate for OSD at DSARC 0 and actions should be taken to achieve such a capability.

C. POINT ESTIMATE METHODS FOR OSD USE AT THE DSARC I MILESTONE

In this section we consider methods that should be used at the critical DSARC I milestone. As discussed earlier a very large percentage of the ultimate support costs to be incurred on an avionics system will be determined by the decisions made at DSARC I.

Although the suitability of the major system under consideration remains to be demonstrated, by DSARC I the Service has determined the major characteristics of the desired system. Our conversations with contractors have led us to conclude that sufficient information on the characteristics of the avionics equipment on a proposed aircraft is available by DSARC I to permit the use of support cost estimating methods with significantly less uncertainty in the outputs than at DSARC 0.

1. Tools to Provide Minimum Required OSD Capability

The EM3 model offers the greatest promise for satisfying the minimum capability required by OSD at DSARC I. This model must have the inputs of engineering judgments with regard to physical characteristics of the avionics equipment and the selection of analogous equipment from the historical data base. Since the avionics equipment is to be identified only to the two-digit WUC level, these engineering judgments are required for a limited number of equipment components.

Considering the importance of the support cost variables in decisions on major systems acquisition, it seems reasonable for OSD to have direct access to a support cost data base built through the use of information produced by the Navy VAMOSC

system and AFLC logistic systems. With such a data base and application of a limited number of engineering judgments, OSD could prepare point estimates that would be sufficiently accurate for an independent DSARC I analysis. Certainly these estimates would be sufficiently accurate to permit a reasonable dialogue with the sponsoring Service on possible costs to be incurred by a proposed system.

2. Tools to Provide Enhanced OSD Capability

OSD capability for developing point estimates independently could be enhanced by adoption of the EM5 model. Although the conceptual approach of this model is the same as EM3, the number of variables is significantly larger. More engineering judgments would be required to use the EM5 approach which should reduce the degree of uncertainty in the outputs.

The AFLC Logistic Support Cost Model, the Navy LCC model, or the CRIER model could be used by the Services in developing avionics support cost estimates for their DCPs submitted for DSARC I decisions. Engineering judgments would be required for many of the inputs but we consider this procedure to be quite feasible. Although these models are too cumbersome for use at the OSD level in preparing independent estimates, the provision of Service estimates generated by these models would be useful for Service and OSD dialogues on support costs.

For the largest of the major system acquisition programs we believe it is reasonable to require the Services to produce EM1-type support cost estimates. The contractors involved in system studies prior to DSARC I can produce such estimates and they should be made available to OSD for the review process.

To summarize at DSARC I, OSD independent avionics support cost analyses should be performed by use of EM3-type models.

The Services should be required to submit cost estimates based on either EM4- or EM1-type model, based on the size of the proposed system acquisition program.

D. OSD METHODS FOR USE AT THE DSARC II MILESTONE

At the DSARC II milestone, source selection has been accomplished and the Service is prepared to move into full-scale development on the proposed weapon system. In our view most of the equipment level decisions have been made by DSARC II and the bulk of the final avionics support costs have been determined. Cost savings can be enjoyed by later actions but they are at the margin and merely represent a "honing" of the systems to achieve maximum efficiency and effectiveness. We see no reason why OSD should accept less than an EM1- or EM4-type model output from the Services at this time.

For independent OSD estimating we suggest the use of the EM5-type model or, as a minimum, the EM3. We recognize that the EM5 model could involve considerable research to secure the necessary input variables. On the other hand, directives with formats could be developed requiring the Services to provide all of the input information needed to use the model.

In our view a fairly comprehensive method must be used for any independent estimates prepared for DSARC II. By this time the hardware components are sufficiently defined that the outputs of broad parametric methods would be of very limited value. The Service and OSD dialogue should involve component-type reviews whereas the value of the parametric methods is that they provide "ball-park" system-type estimates.

E. TOOLS FOR OSD USE IN CONDUCTING AVIONICS COMPONENT TRADE-OFF ANALYSES

This section addresses the question of support cost estimating methods that might be useful in conducting trade-off

analyses on individual avionics equipments such as fire control radars.

Our task order required us to review industry and Service data and management systems to determine the extent to which they contain high-cost avionics subsystem data. As stated elsewhere in this paper we believe that the Navy VAMOSC data base contains suitable data to use in addressing questions related to individual avionics component support costs. In the Air Force the IROS system provides useful information for this type of analysis although we are not satisfied that the IROS system encompasses all of the base and depot costs that should be considered.

To provide OSD with a suitable capability to conduct avionics component trade-off studies, the first step is to create a data base of the kind required to support an EM3-type model. However, the data base should include information at the 5-digit as opposed to the 2-digit WUC level. Such a data base would include support cost information on a long list of avionics components for which physical data characteristics would also be available. Regression equations at the 5-digit WUC level in an EM3 model should provide a suitable capability to conduct trade-off analyses. In some instances it might be necessary to exercise judgment on analogous systems.

The key to success with the EM3 model is the development of a reasonably accurate data base and conduct of high quality statistical analyses. As stated elsewhere, we believe this is feasible assuming sufficient resources are applied to the task.

F. CONCLUSION

In this chapter we have provided our recommendations on the best avionics support cost estimating methods for OSD to use at the DSARC 0, I, and II milestones.

We consider it very feasible to develop and use these methods; in fact, we consider it essential if OSD is to implement its policies of incorporating life cycle costs as an important independent variable in the major system acquisition process. Furthermore, we consider that these methods should be developed and used as evidence that OSD is serious about the importance of these life cycle cost variables. A thorough and vigorous effort to pursue the support cost estimating problem would be a major step in establishing and maintaining credibility with the defense contractor community in this regard.

In some of the proposed models engineering judgement inputs are required to permit the models to produce the desired outputs. These judgements should be available to OSD from various sources including the Services and, perhaps, the OSD staff. In some cases it might be necessary or more appropriate to secure assistance from independent contractor sources. Considering the assumed importance of the support cost variables in OSD decision-making, it is clearly reasonable to expend sufficient resources on professional assistance to assure that the best possible outputs are obtained from OSD estimating methodologies.

Models are abstract representations of reality and will always produce uncertain outputs. These outputs are useful in assessments of order-of-magnitude and relative values. We believe that in the DSARC process these outputs should be augmented by detailed OSD-level engineering and cost analyses of estimates and their associated variables produced by the Services and contractors in supporting their DSARC submissions. These analyses should be thoroughly and objectively performed. Considering the importance of these major programs and the time required to develop estimates in the Services and review them at the OSD level we believe it is reasonable for OSD to

conduct in-depth line item type reviews of Service-submitted support cost estimates. These reviews would be designed to ensure that the best judgments and best data have been used in developing the variables and producing the outputs that will be so important in decision-making.